WS No. 19 Mark III

ELECTRICAL AND MECHANICAL ENGINEERING REGULATIONS
(By Command of the Army Council)

TELECOMMUNICATIONS
A 170

D.C. TELEGRAPHY

Erratum

Note: This Page 0, Issue 1, will be filed immediately in front of Page 1, Issue 2, dated 26 Nov 1948.

1. The following amendment will be made to the regulation.

2. Page 4, Fig 3, from LAND LINE and CABLE messages

Delete: 'W'
Insert: 'G'

EME8c/2146

D.C. TELEGRAPHY

Note: This issue, Pages 1 to 6 and 13 to 16, supersedes Pages 1 to 6 and 13 to 16 of Issue 1, dated 12 Mar. 1948. Items and paras. marked thus ● have been amended.

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LIST OF FIGURES

GENERAL

Scope of E.M.E.R.

1. This E.M.E.R. is the first of a series of three dealing with general aspects of telegraphy. The others are :—

(*a*) V.F. telegraphy (Tels. A 171)

(*b*) Teleprinters over radio links (Tels. A 172).

Uses of D.C. telegraphy

2. Telegraphy is best suited to the transmission of reports and orders which are not likely to require further amplification or explanation, since communication takes place through an operation and it does not normally permit of personal contact between individuals as does telephony.

3. Most important long-distance telegraph links are, nowadays, made by land lines carrying a modulated voice-frequency current or by radio. An exception to this is the case of submarine cables, where difficulties in the design of submersible amplifiers make the use of D.C. desirable.

4. However, all telegraph instruments transmit D.C. and require D.C. to operate their receivers, hence, whatever system may be used to link stations, some portion of the connection from instrument to instrument must be made by a line carrying D.C.

5. Even the lines linking instruments to the station sending and receiving apparatus may be several miles in length and, unless the context demands otherwise, the remarks which follow should be taken as applying to such lines as well as to D.C. lines used to link stations.

METHODS OF SIGNALLING

General

6. Fundamentally, telegraphy consists of switching a current on and off in a pre-arranged manner. This gives two possible conditions at the receiving end, termed *marking* and *spacing*. In practice, advantages are obtained by substituting a current of reversed polarity for the current-off condition (see para. 96), and this gives rise to the use of two further terms—*single-current signalling* and *double-current signalling*.

Single-current signalling

7. This is the simple on-off system and is illustrated in Fig. 1. A battery, a switch (say, a hand-key or relay tongue) and a receiver are connected in series, and signalling is carried out by opening and closing the contact, producing a series of pulses of direct current.

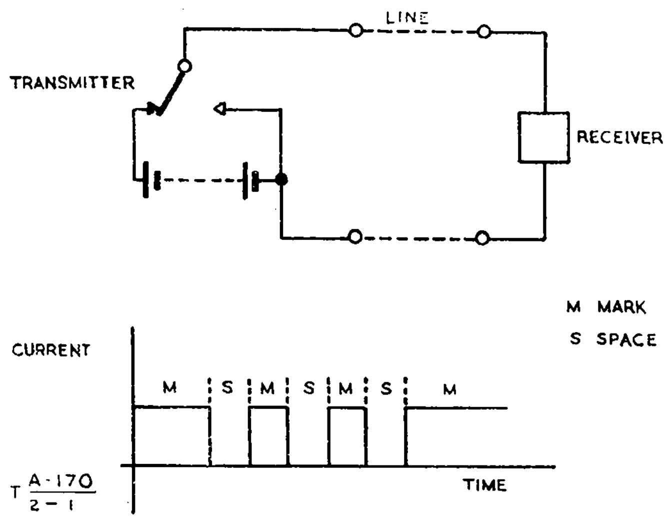

Fig. 1—Single-current signalling

Double-current signalling

8. This is the reversed-polarity system and is illustrated in Fig. 2. The circuit and system of operation are exactly the same as for single-current working except that, instead of switching the current on and off, the contact changes it from a +ve to a −ve direction of flow.

9. It will be seen that, in Fig. 2, the +ve pole of the battery to line is termed *mark*, and the −ve pole to line is termed *space*. This conforms to the international standard (C.C.I.T.) convention, but in G.P.O. and Service practice the terms are normally reversed, −ve to line being mark and +ve to line being space. The general principle is, of course, not affected by this change, but where confusion may arise the convention used should be made clear.

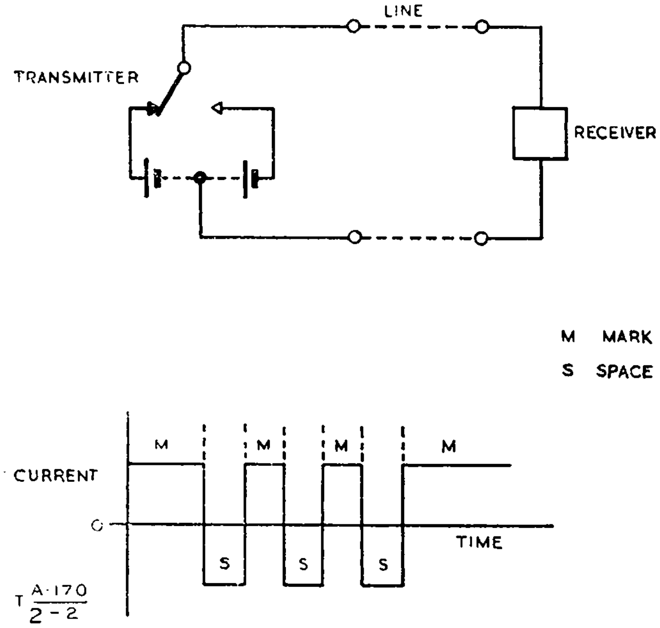

Fig. 2—Double-current signalling

TELEGRAPHIC CODES

General principles

10. Using only two different signalling conditions (mark and space), it is obviously not possible to transmit information without some form of code. In practice, therefore, multi-unit codes are used.

11. If a code is adopted in which every character is represented by two current pulses, then we have four (i.e., 2×2) possible combinations :—

MM MS SM SS

12. If each character is represented by three pulses, then we have eight ($2 \times 2 \times 2$) possible combinations :—

MMM	MMS	MSM	MSS
SMM	SMS	SSM	SSS

Character	*Code*	*Character*	*Code*
A	•—	N	—•
B	—•••	O	———
C	—•—•	P	•——•—
D	—••	Q	——•
E	•	R	•—•
F	••—•	S	•••
G	——•	T	—
H	••••	U	••—
I	••	V	•••—
J	•———	W	•——
K	—•—	X	—••—
L	•—••	Y	—•——
M	——	Z	——••
1	•————	6	—••••
2	••———	7	——•••
3	•••——	8	———••
4	••••—	9	————•
5	•••••	0	—————
∅ *Apostrophe '	•————• WG	*Hyphen -	—••••— DU
∅ *Underline —— ...	••——•— UK	*Inverted commas " ...	•—••—• RR
*Equals = ...	———— MM	*Brackets) (... ...	—•——•— KK
*Stop	•—•—•— AAA	Oblique /	—••—• DN
*Question mark ? ...	••——•• UD or IMI	Maltese cross ✠ (see Note 4)	•••—• SN or VE
Reduce RED	See Note 1	Carriage return and line feed	—•••— BT
Maximum MAX ...	See Note 2	Space bar	(See Note 3)

Notes: 1. Depression of this key reduces the inter-letter spacing to 1 unit (no feed holes).
2. Depression of this key feeds the tape 25 units (12 feed holes).
3. Depression of this key is used as the interval between words and feeds the tape 5 units (2 feed holes).
4. This was formerly used as an "erase" sign.
* Obtained by holding down the "Reduce" key whilst the letter keys indicated are depressed.
∅ Not provided on the morse printer.

Table 1—Morse code

●13. Every time the length of the character is increased by one pulse, the number of possible combinations is doubled. A still greater increase is possible if the number of pulses stipulated is the maximum permitted and smaller numbers of pulses may be used.

14. For example, if we represent the characters by any number of pulses up to three, we have fourteen (2+4+8) possible combinations :—

M S
MM MS SM SS
MMM MMS MSM MSS SMM SMS SSM SSS

15. When signals are received aurally, it is not easy to distinguish between similar signals containing a larger number of current pulses, e.g., MMMMS and MMMSS. To overcome this, it is usual to substitute short marks and long marks for the normal marks and spaces, and also to employ not more than five pulses per character—giving 32 characters if each one is five units long, or 62 if the length varies up to five units.

16. When the short-mark-long-mark system is used, the space signal is used to separate successive marking signals. The number of possible combinations is, of course, the same as in the ordinary mark-space system.

Early codes

17. In the simplest codes, certain pre-arranged words or sentences are represented by a series of short and long marking pulses separated by spaces, and indicated at the receiving end by the deflection of a galvanometer needle or operation of a bell. This type of code is still widely used in cases where only standard messages are likely to be passed, for example, to maintain communication between railway signal cabins.

●International morse code

18. A simple extension of this early type of code is the international morse code, in which a series of pulses is used to represent a single letter or figure instead of a complete word, and it is thus possible to build up any desired message.

19. The code, which was originally used chiefly for audible reception, uses short marks and long marks, the former being termed *dots* and the latter *dashes*. Each dash is three times the length of a dot. The standard space signal is one dot in length, each dot or dash being separated by one space, letters by two spaces and words by three spaces.

20. A portion of a typical land-line morse message is shown in Fig. 3, where it is contrasted with the same message in cable morse code.

●Cable code

21. This code is a development of the original morse code, intended for machine reception. The machines used can readily distinguish between marks and spaces if double-current signalling is used, hence both the dots and dashes are replaced by signals of dot length, marking for dots and spacing for dashes giving a simple mark-space code. The elimination of the dashes makes a big increase in transmission speed possible.

22. Successive signalling elements may be separated by an interval of zero current, approximately half a unit in duration, to facilitate reading when using certain types of receiver which trace the waveform in ink on a tape, but this is not essential and is not shown in the message in Fig. 3.

5-unit machine codes

23. The present tendency in telegraph practice is to employ machines fitted with keyboards similar to that of a typewriter which, on depression of a key, automatically send the correct code combination to line, and print the selected letter when the code combination is received at the other end. This considerably reduces the operator skill required and gives higher operating speeds than manual morse code working.

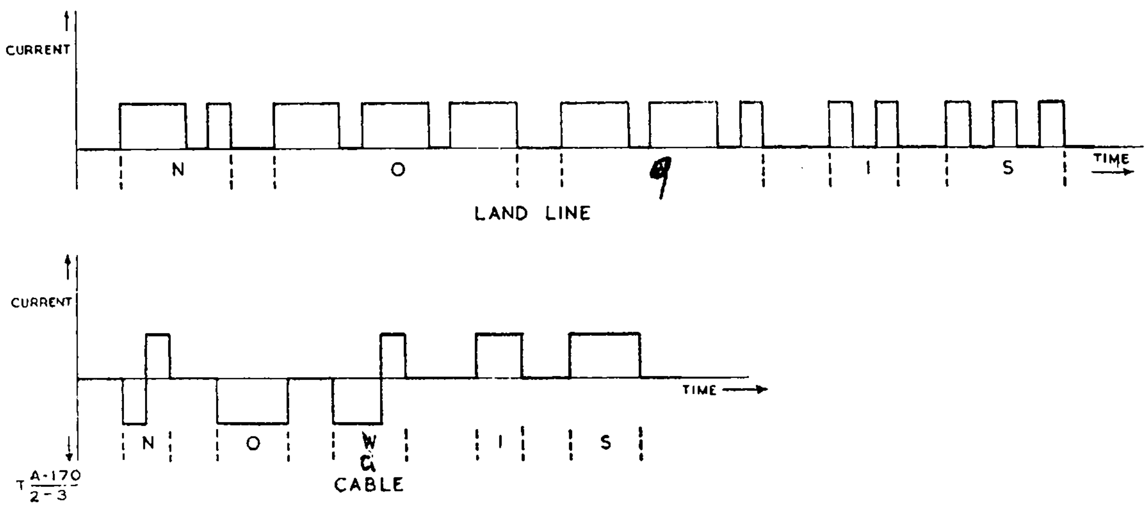

Fig. 3—Morse code messages

24. For such machines, the ordinary morse code has two fundamental disadvantages.

(*a*) The machine must be able to distinguish between the dots and dashes on a time basis, which is difficult to arrange at high speeds.

(*b*) The machine must be able to distinguish between characters represented by code combinations of different lengths, e.g., E (one dot) and ZERO (five dashes with four intervening spaces).

(*c*) Unless the speed is brought down to that of the longest letter the machine cannot print directly.

25. Successful morse code machines have been designed and the use of cable morse code does, of course, remove the first objection, but special codes have been developed for machine use and these reduce the difficulties in design.

26. The essential features of these codes are that signalling on a simple mark-space basis, using either single-or double-current working, and that all characters are represented by five current pulses.

27. In addition, each character is preceded by a mark pulse, one unit in length, to start the receiving machine, and a space pulse, normally also one unit in length, to stop it. Hence the complete signal is actually seven units in length. A typical signal is shown in Fig. 4(*a*).

28. Prior to the international standardization of signals seven units in length, British machines operated on a signal length of 7½ elements, as shown in Fig. 4(*b*), the final pulse (stop signal) being increased to 1½ units, and present-day machines on the inland links still use this code although most of them have receivers capable of working on a 7-unit code.

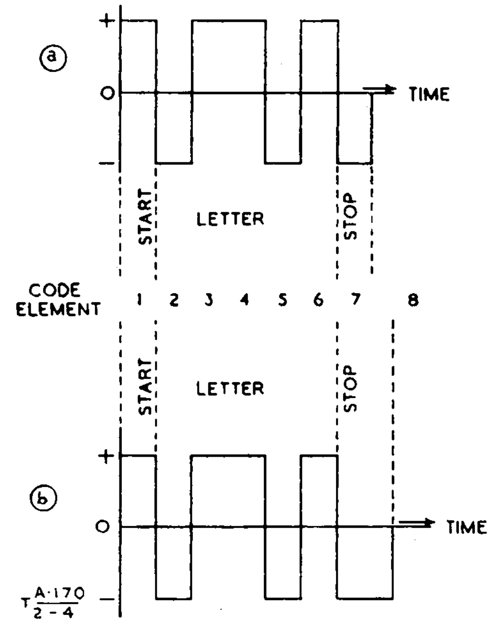

Fig. 4—5-unit code signals

Character		START	*Code*	STOP	*Character*		STOP	*Code*	START
Primary	*Secondary*				*Primary*	*Secondary*			
		○		●			○		●
A	—		● ● ○ ○ ○		P	0		○ ● ● ○ ●	
B	?		● ○ ○ ● ●		Q	1		● ● ● ○ ●	
C	:		○ ● ● ● ○		R	4		○ ● ○ ● ○	
D	WHO ARE YOU		● ○ ○ ● ○		S	;		● ○ ● ○ ○	
E	3		● ○ ○ ○ ○		T	5		○ ○ ○ ○ ●	
F	%		● ○ ● ● ○		U	7		● ● ● ○ ○	
G	@		○ ● ○ ● ●		V	=		○ ● ● ● ●	
H	£		○ ○ ● ○ ●		W	2		● ● ○ ○ ●	
I	8		○ ● ● ○ ○		X	/		● ○ ● ● ●	
J	BELL		● ● ○ ● ○		Y	6		● ○ ● ○ ●	
K	(		● ● ● ● ○		Z	+		● ○ ○ ○ ●	
L	)		○ ● ○ ○ ●		CARRIAGE RETURN			○ ○ ○ ● ○	
M	.		○ ○ ● ● ●		FIGURE SHIFT			● ● ○ ● ●	
N	,		○ ○ ● ● ○		LETTER SHIFT			● ● ● ● ●	
O	9		○ ○ ○ ● ●		LINE FEED			○ ● ○ ○ ○	
					SPACE			○ ○ ● ○ ○	

Note: Elements which cause the setting of teleprinter combination discs or perforation of reperforator tape are shown thus ●. They are often referred to as *marking* elements, whilst those of the opposite kind ○ are known as *spacing* elements.

Each group of code elements is preceded by a start signal and succeeded by a stop signal. The latter may be of 1 or 1½ units duration.

Table 2—5-unit code

Baudot code

29. One of the first 5-unit machine codes was the Baudot. The machine operator set up five keys simultaneously, in comformity with the code, thus producing a mark-space combination which was then sent to line.

30. This system of operation has, however, now been displaced by the teleprinter working on the Murray code, which requires less skill from the operator.

Murray code

31. The Murray code, a development of the Baudot system, is also a 5-unit code, but the normal system of operation is for the depression of a single letter key to send to line the required combination automatically without special manipulating by the operator.

32. Table 2, which uses the British convention for marks and spaces, shows the Murray code, and it will be noted that secondary characters are included. This increases the number of characters which can be transmitted without increasing the complexity of the code.

●33. The same code is sent to line for both primary and secondary characters, but a change in the mechanical condition of the receiver is made by sending a special code combination to line before transmitting the character. These code combinations are the *letter shift* and *figure shift*.

NON-CODE SYSTEMS

General

34. Instead of using one of the standard telegraphic codes already discussed, information may be transmitted by systems which involve scanning of the material to be transmitted and reproduction at the receiving end by a similar process. There are two classes of system in use :—

(1) Mosaic telegraph machines which are keyboard-operated and reproduce individual letters as they are typed.

(2) Photo-facsimile machines which can reproduce complete pages of print, drawings, photographs, etc.

Mosaic telegraph

35. Mosaic telegraph machines actually synthesize the character to be transmitted mechanically, but the effect is the same as if a grid had been superimposed on the letter and then scanned as shown in Fig. 5.

36. The machine sends a mark to line when the square being scanned covers a portion of the letter, and space when it is blank. Thus the black squares in the figure represent marks and the white ones spaces.

37. At the receiving end, a pen, or similar device, reproduces the letter on a tape by marking it when a mark signal is received and lifting clear when space is received.

Facsimile systems

38. The general principle of photo-facsimile reproduction is for the transmitter to scan the picture in narrow bands and produce a current proportional to whiteness or blac ness of the print. Line drawings, however, may be transmitted by switching the current on and off as in other systems of telegraphy.

39. At the receiving end, an image is built up line by line in accordance with the current sent. A photographic negative is usually produced, but for black and white drawings the current may operate a pen in a similar manner to that used in keyboard machines.

40. The principle of the photographic apparatus used for this system is shown in Fig. 6. The picture to be transmitted is mounted on a drum, which is rotated and traversed on a screw thread so that all parts are brought successively under a narrow beam of light.

41. The light reflected is picked up by a photo-electric cell, which produces a current varying in magnitude according to the amount of light falling on it. This current is sent to line as a modulated V.F. and at the receiving end a film, similarly wrapped on a drum, is exposed to a beam of light whose intensity varies with the curre received, thus producing a negative.

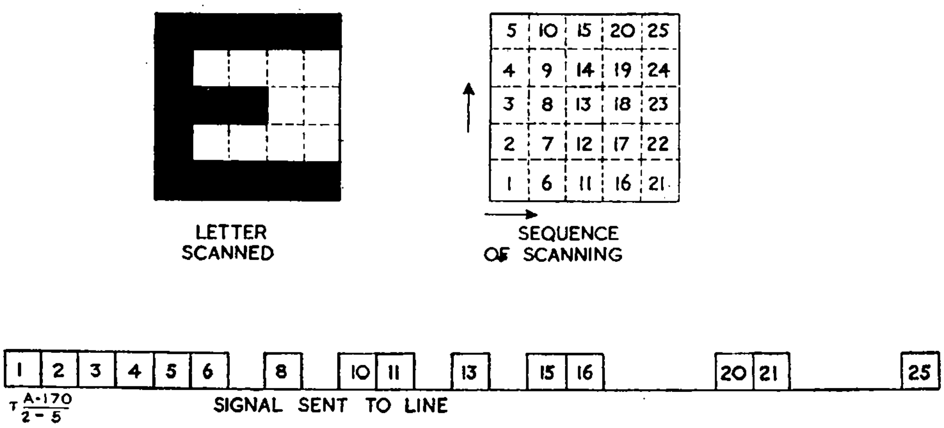

Fig. 5—Transmission of letter E by mosaic telegraph machine

42. This apparatus is, of course, suitable for transmitting any sheet material, such as drawings, photographs, maps or even complete pages of printed matter.

45. The number of these shortest signal elements which may be sent in one second is the working speed in bauds.

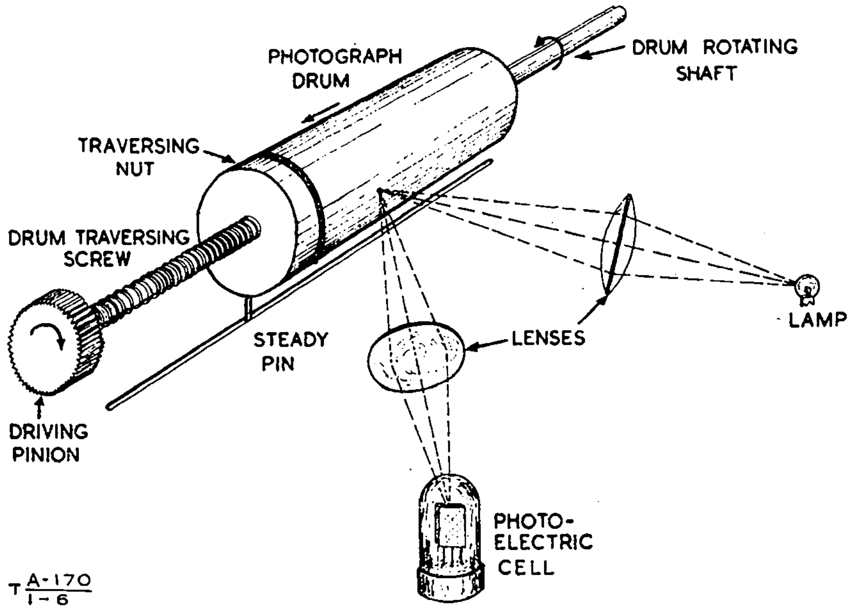

Fig. 6—Transmitter for photographic reproduction

SIGNALLING SPEEDS

General

43. Two measures of signalling speed are employed :—

(*a*) The time taken to send the shortest signal element.

(*b*) The number of words which may be sent in one minute.

The baud

44. The time taken to send a letter depends, in the first place, on the time taken to send the shortest signal element, say, one dot in morse code or one marking or spacing pulse in Murray code.

46. For example, a Teleprinter 7B uses a 5-unit code, each pulse being 1/50th of a second (20 msec.) long. Its working speed is, therefore, 50 bauds.

Words per minute

47. The speed in words per minute, also known as cadence speed, is determined by assuming certain standard conditions of working. These are :—

(*a*) That each word consists of six characters (or five letters and a space).

(*b*) That, in morse working, an average letter is eight dots in length.

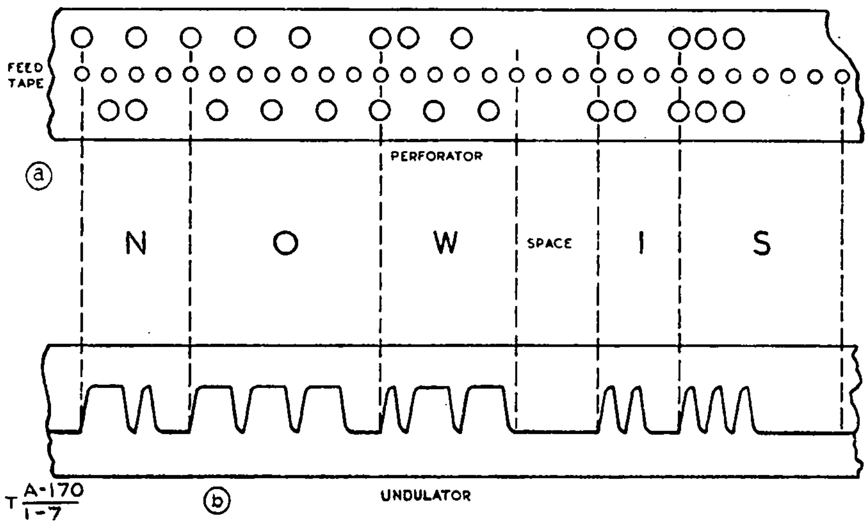

Fig. 7(a)—Morse code perforator tape. (b)—Morse code undulator tape

48. In photo-facsimile systems, both speed and definition (amount of detail) depend on the number of scanning lines per inch of traverse and the number of lines scanned per minute.

AUTOMATIC TELEGRAPH TRANSMISSION

General

49. To secure the maximum utilization of radio links, which may only be in operation for a few hours at a time, it has proved necessary to devise a means by which morse or 5-unit code messages may be stored at the sending end and then transmitted at comparatively high speeds when the link becomes available. This is done by the use of tapes, perforated to represent the code signals of the message, which are fed into automatic transmitters.

50. The tapes are prepared either on keyboard perforators, which are operated in a similar manner to a typewriter but produce a punched tape instead of a printed sheet, or on reperforators which produce a similar tape when actuated by signals received from line.

51. Morse code tapes (see Fig. 7(*a*)) have two holes punched in them for each dot or dash, one hole being vertically below the other for a dot or displaced to the right for a dash.

52. Unit code tapes (see Fig. 8) have up to five holes punched vertically below each other to represent the code elements and a sixth hole which acts as a feed hole. The tape is perforated only on receipt of a – ve pulse (mark signal in British practice).

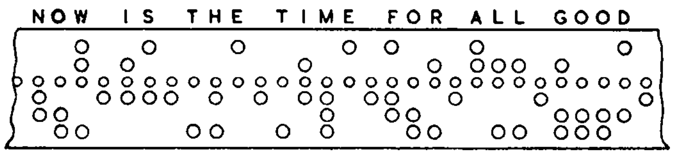

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Fig. 8—5-unit code perforator tape

53. Both these tapes suffer from a disadvantage in that skilled operators are required if the message on the tape is to be read before transmission, since the perforation in the tape prevent a printed version of the message from being made on it. For 5-unit code machines, therefore, special tapes have been developed on which the message can be printed at the same time as the tape is perforated.

54. The tape used is shown in Fig. 9. The perforations are not complete and a hinged flap is left after punching; this flap is then bent back so that the tape is complete again, thus making it possible to print legible characters.

55. So that each character may be perforated and printed simultaneously, there is a lag of several spaces between the perforations and the corresponding character as indicated in the figure. This lag is about eight characters in British practice.

56. The name *chadless tape* has been used to distinguish this type of tape from the fully perforated type.

Transmitters

57. The automatic transmitters used are fitted with spring-loaded plungers, these plungers are normally held down by the tape, but when a perforation appears, the plunger rises. The plunger-down position corresponds to space and the up position to mark (British convention) and the appropriate signals are sent to line automatically.

Receivers

58. At the receiving end, the signal may be recorded on another perforated tape by a reperforator or fed int either a morse printer or a 5-unit code teleprinter, as appropriate, which produces a printed version of the message.

59. An alternative method used for morse reception is to plot the current waveform on an undulator tape (see Fig. 7(*b*)) and then decode it.

COMPARISON OF CODE AND NON-CODE SYSTEMS

General

60. From a military point of view, the value of a particular means of transmitting information depends primarily upon :—

(*a*) The type of information which can be transmitted.

(*b*) The speed of transmission and accuracy of reproduction.

(*c*) Operating skill required.

(*d*) Portability, not only of transmitter and receiver, but also of all associated equipment.

(*e*) Degree of security provided.

(*f*) First cost and maintenance charges.

(*g*) Number of operators required.

(*h*) Robustness.

61. The order of importance depends, of course, on the particular purpose for which the equipment is required.

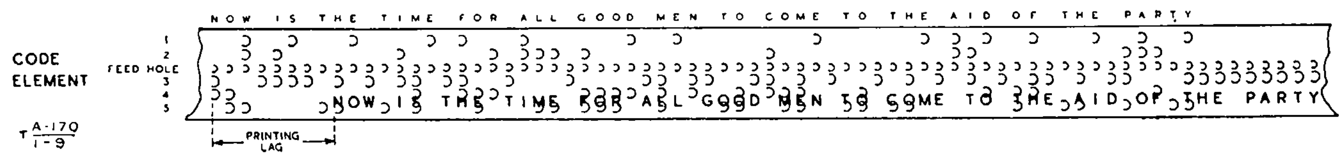

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Fig. 9—Printed and perforated tape

Morse and 5-unit codes

62. The morse code was originally designed for manual operation, and the equipment required for such a system is very simple and light in weight, but a high degree of operator skill is required and an over-all speed in excess of 15 words per minute is not likely to be maintained for any length of time.

63. Teleprinters, on the other hand, are comparatively complex and heavy, but an operator should attain a speed of 25-30 w.p.m. after a short period of training.

64. The increasing use of R/T and field telephones has largely negatived the advantages offered by the lightness of manual morse equipment, and the teleprinter has found favour as being superior where portability is not so important.

65. When used with automatic transmitters, the considerations involved are somewhat different. The keyboard perforators and printing equipment for both morse and 5-unit codes are different mechanically but their general characteristics are similar.

66. The speed which can be attained in automatic operation of teleprinters ranges from about 60 up to the C.C.I.F. standard of 72 w.p.m. compared with some hundreds of w.p.m. with high-speed morse equipment. Against this, however, the frequency band-width required for transmitting high-speed morse over a radio link is much greater than that for a teleprinter, and the total traffic capacity of any given link is made far greater by the use of teleprinters, as several can be operated simultaneously without increasing the band-width beyond that required for morse.

67. It is clear that the increase in the traffic capacity of a radio link obtained by using teleprinters reduces the number of senders and receivers required and, hence, effects a considerable saving in first cost and maintenance charges even though additional V.F. telegraph equipment (see Tels. A 171) is required.

68. The present trend is for most morse systems to be replaced by speech or 5-unit code equipment.

5-unit code and non-code systems

69. Mosaic telegraph machines are lighter in weight than teleprinters and may be able to operate over poorer lines than either teleprinters or telephones, but they are slower in operation.

70. Keyboard facsimile machines will not work in conjunction with teleprinters, nor is automatic ciphering equipment available for use with them.

71. Photographic facsimile, when used for transmission of typewritten information, is comparable in speed with teleprinter working, but the need for an associated typewriter and photographic developing equipment must be borne in mind.

72. In general, the photo-facsimile equipment is heavier than a teleprinter, but reasonably portable types have been designed.

73. Photo-facsimile is, of course, the only means available for transmitting photographs, drawings, etc., but, for ordinary message transmission, it suffers from the same disadvantages as high-speed morse in that a comparatively wide frequency band is required for transmission over radio links.

FACTORS AFFECTING OPERATION

General

74. The ideal D.C. telegraph signal is a rectangular pulse of current which rises instantaneously from zero to a maximum, remains steady and then returns instantaneously to zero.

75. In practice, the electrical characteristics of the circuit cause the pulse to become attenuated and distorted in transmission, with the result that it tends to change to the form shown in Fig. 10.

76. Attenuation limits the distance over which effective signals may be sent and, in a long line, may be so great that the receiver will not respond.

77. Distortion, as will be seen later, may cause false signals to be received if the signalling speed is too high.

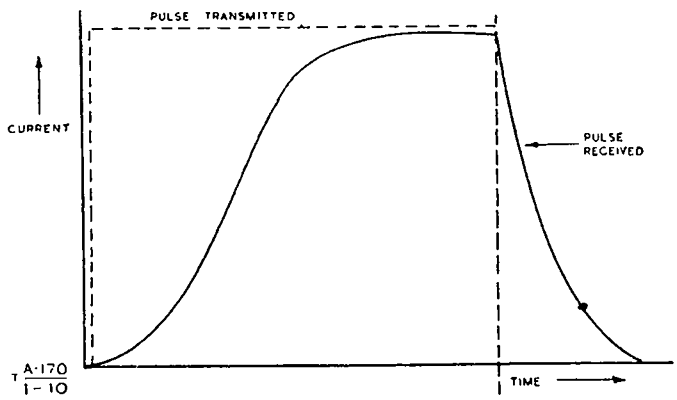

Fig. 10—Distortion of pulse

78. The chief factors affecting the attenuation and distortion of the signal are :—

(*a*) The primary constants of the transmission line—its resistance, inductance, capacitance and leakance.

(*b*) The characteristics of the receiver and any intermediate relays—notably their inductance and mechanical inertia.

(*c*) External interference and faulty adjustment of the receiver and relays.

79. Of these factors the most important is usually the line, but the receiver is dealt with first so that the effect of distortion may be explained.

Effect of receiver

80. Telegraph receivers are basically electromagnets with single-current signalling ; a certain minimum value of current will be required to operate them, and once this has been reached the receiver will remain operated until the current again falls below this value. In double-current signalling, the same considerations apply, but a reversal of polarity is also necessary. Normally the change-over does not take place precisely at the critical value, as the inertia of the armature delays it slightly.

81. The more rapidly the change of current can be effected, the greater the possible speed of signalling, but a limit is placed on the rate of change by the inductance of the receiver.

82. The rise and fall of current in an inductive circuit when a D.C. pulse is applied is shown in Fig. 11. The time taken for the current to read any given value is proportional to $\frac{L}{R}$, where L is the inductance and R the resistance of the receiver circuit.

83. The result of having too slow a rise and fall in current is illustrated in Fig. 12, where the distorted waveform of the morse code letter S is shown. The dotted lines indicate the rise and fall of current which would occur if the signalling condition (i.e., mark or space) were maintained for a sufficient length of time.

84. Under the conditions shown, the receiver would probably fail to respond correctly and the three dots would actually be received as a continuous note. Clearly, to give accurate reception, the speed of signalling would have to be reduced to leave time for a greater rise and fall of current.

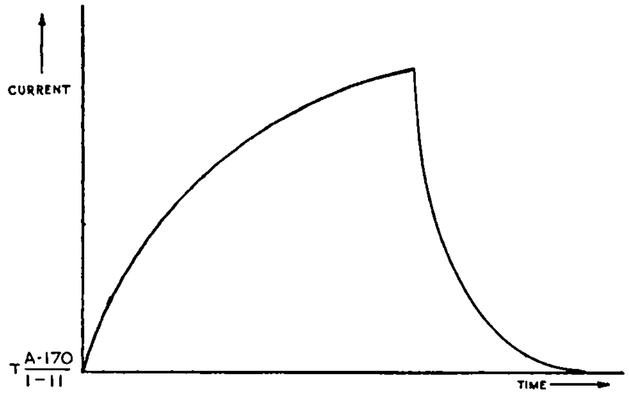

Fig. 11—Rise and fall of current in an inductive circuit

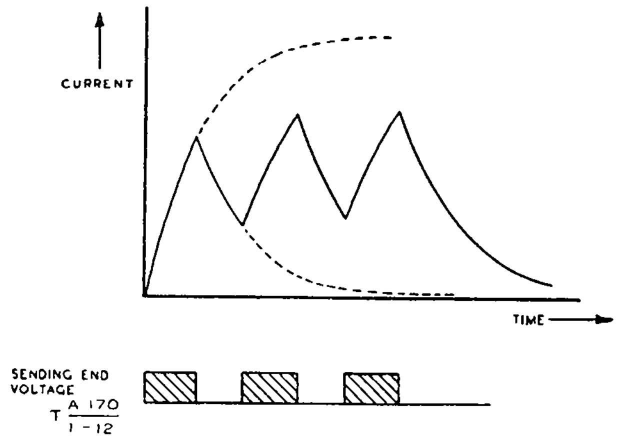

Fig. 12—Distorted letter S (Morse code)

85. The distortion due to the receiver may be reduced by the employment of a compensating network. Since the time for the current to reach any given value is proportional to $\frac{L}{R}$, an increase in the resistance of the circuit will increase the rate of change of the current and hence the speed of signalling. Fig. 13 shows the improvement obtained by the use of different values of resistance.

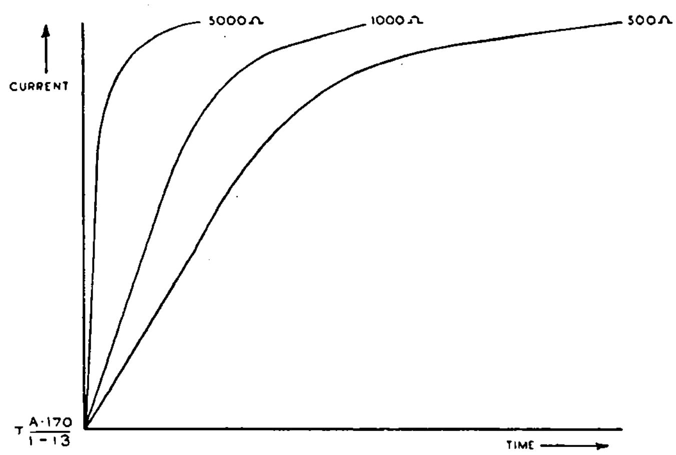

Fig. 13—Effect of extra resistance on pulse onset

86. Although this simple network is quite suitable for shorter lines, its use is limited by the fact that the increased resistance demands a corresponding increase in signalling voltage.

87. To overcome this difficulty, the circuit shown in Fig. 14(*a*) may be used. If C is increased beyond a certain critical value, then a damped oscillation will be produced whenever a voltage is applied across the circuit. This oscillation causes a rapid rise in the current in the receiver circuit itself, with the result that the waveform becomes as shown in Fig. 14(*b*). It will be seen that the reduction in distortion has produced a shorter pulse, and hence increased signalling speed.

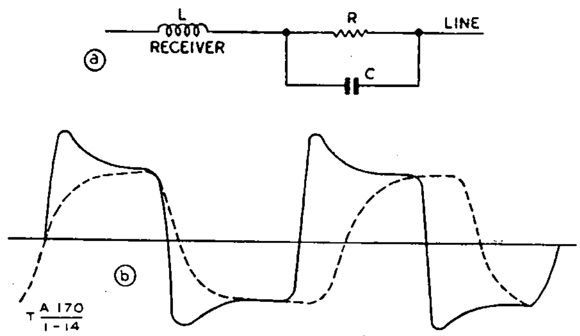

Fig. 14(a)—Compensating network
(b)—Modified pulse form (double-current signalling)

Effect of transmission line

88. Some general notes on transmission lines are given in paras. 120—148; the particular considerations affecting telegraph operation are dealt with below.

89. The leakage and resistance of the line set a limit to the distance over which signalling may be carried out without some form of repeating device. This range may, however, be increased by the use of relays, which are more sensitive than the normal telegraph receivers, and can be used to switch an auxiliary source of current on and off, in accordance with the signals received, thus operating the receiver.

90. Relays may also be used to repeat the signals at intermediate points in the line, but few D.C. telegraph circuits are nowadays of sufficient length to justify this and the relay is usually situated close to the receiver.

91. Any transmission line may be considered to have a series of capacitors between the two conductors (see para. 121). When a signalling voltage is applied to one end of the line, all these capacitors must be charged in turn before the received current can reach its maximum value, and this produces a build-up of current at the receiving end similar to that shown from A to B in Fig. 15. For a short time, known as the silent interval, the current is practically zero, it then rises gradually until the maximum value is reached.

92. When the signal pulse ceases, the current again decays gradually along the curve B—C in Fig. 15. The pulse during transmission thus becomes distorted in a similar manner to the pulse in the receiver.

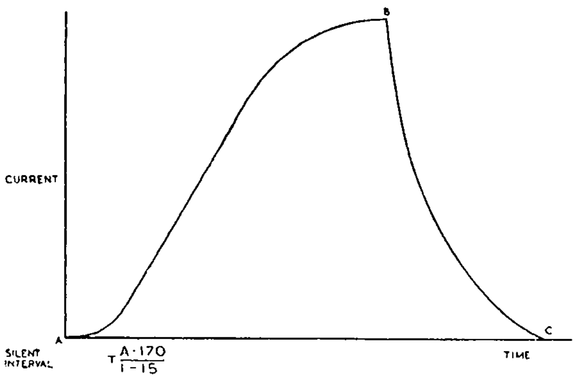

Fig. 15—Distortion in transmission line

93. One method of neutralizing the effect of line capacitance is to increase the line inductance. This extra inductance may either be added in "lumps", by means of loading coils, or uniformly, by wrapping the line with a ferro-magnetic material. The latter method is more expensive and its use is confined to submarine cable.

94. Another method is to use double-current signalling (see para. 8). The application of a reversed polarity to the line, instead of merely a zero voltage, causes a much more rapid discharge of the line capacity, thus reducing the tendency for the decaying pulse to be extended; at the same time the receiver responds to change of polarity rather than growth of current and is made more sensitive.

95. Double-current signalling also helps to overcome the effect of receiver inductance. It is in almost universal use in British teleprinter systems but the single-current system is employed by some other countries.

PRACTICAL CIRCUITS

General

96. The systems of working used in telegraphy are of two basic types:—

(1) Simplex.

(2) Duplex.

In simplex working, messages are transmitted over the circuit in only one direction at a time. In duplex working, they may be sent and received by both ends simultaneously.

97. Examples of the circuits used in teleprinter working are given below. For morse code and other methods of working, the circuits used are basically similar, but neither the local record facility nor the automatic send-receive switch is provided, though a manual send-receive switch can, of course, be used.

2-wire simplex operation, using earth return

98. This really consists of two separate 2-wire circuits, one for each direction of transmission, thus requiring four wires, but in practice one wire of each circuit is replaced by a common earth return.

99. Signals from A to B are transmitted over L1 and the earth return, and those from B to A over L2 and the earth. The low-pass filter is designed to prevent the higher harmonics from passing to line, thus improving signalling conditions. The variable resistor in the receiving circuit is a simple form of compensating network (see para. 87) and permits the receiver current to be adjusted to a suitable value.

100. It should be noted that this system comprises two independent circuits, thus providing a duplex traffic facility. Frequently it is modified to provide simplex traffic only but with a local record of the messages transmitted.

101. The modified circuit is shown in Fig. 16(*b*). The auto send-receive switch is normally in the receive position, but as soon as the local teleprinter commences transmitting, it changes to the send side, thus by-passing a proportion of the send-line current, via the variable resistor, to the receiver which prints the local record.

Switched simplex

102. In this circuit (see Fig. 17), the same line is used for sending and receiving and a local record facility is provided.

103. The auto S/R switch is in the line circuit and, again, is normally in the receive position, but changes to send when the local teleprinter is transmitting and permits a local record to be printed.

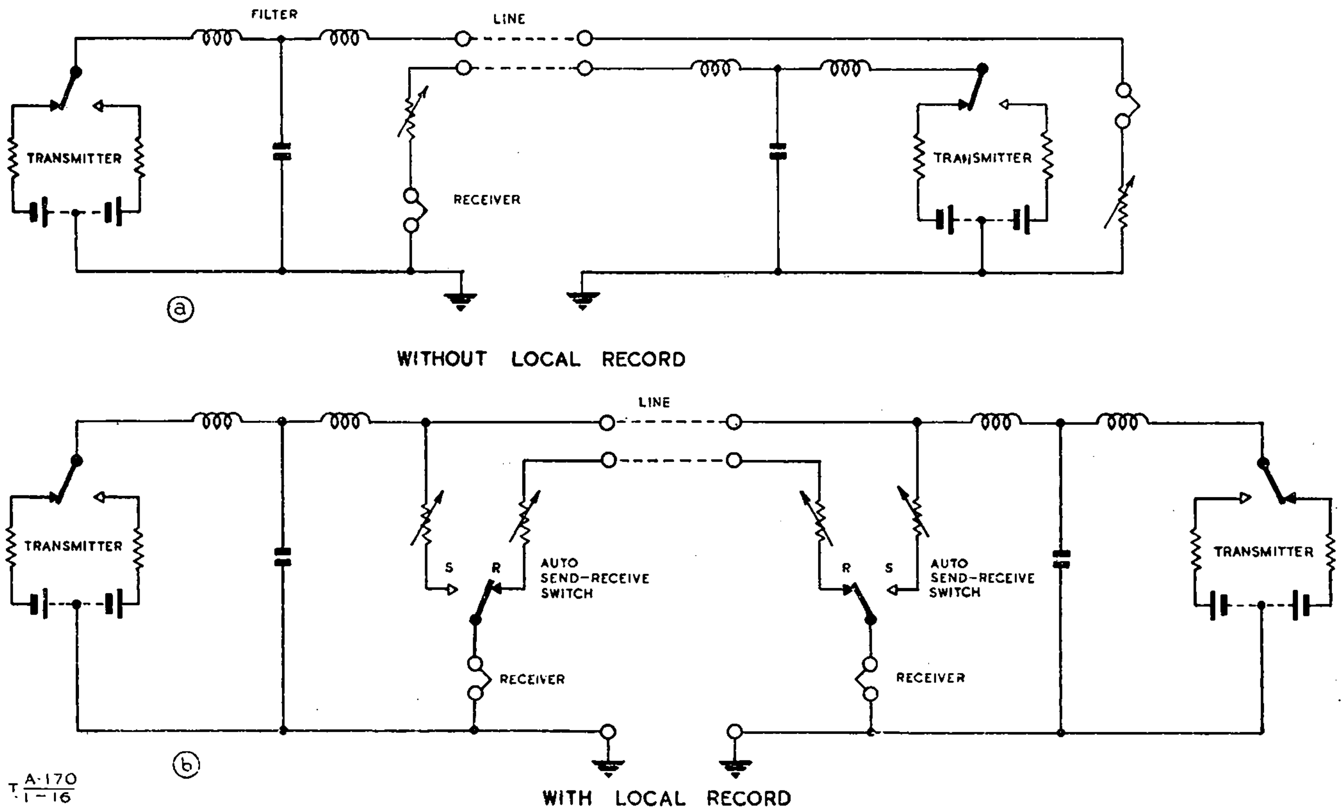

Fig. 16—2-wire simplex operation, using an earth return
(a) without local record
(b) with local record

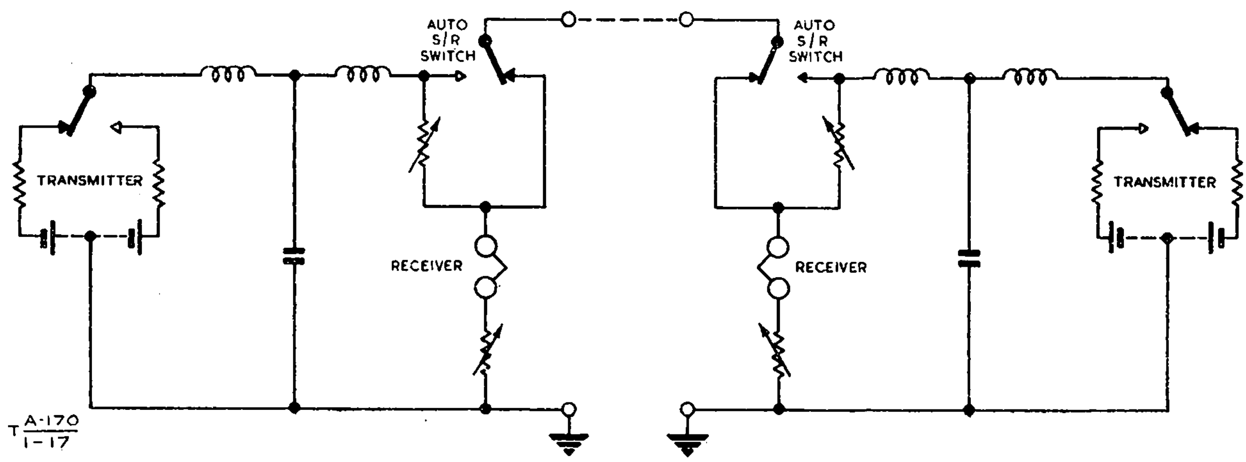

Fig. 17—Switched simplex

Full duplex

104. A number of different circuits for duplex operation exist, a typical one being shown in Fig. 18 (the send filter has been omitted for clarity). Messages may be sent both ways simultaneously over the same pair of wires, or one wire with earth return, but a local record facility is not provided.

105. In such a system, the following conditions must be satisfied :—

(*a*) When both transmitters are sending mark to line, the receivers at both ends must mark.

(*b*) When both transmitters are sending space, both receivers must space.

(*c*) When only the transmitter at A sends space, the receiver at B must move to space whilst that at A continues to mark, and vice versa.

106. Considering the conditions as shown in Fig. 18, the batteries are sending equal and opposite currents to line, as indicated by the single arrows, thus no current actually flows in the line circuit and the receivers are held to mark by the currents in the balance network.

107. When both transmitters change to space, the currents are reversed, as indicated by the double arrows, and the receivers change to space.

108. When only the transmitter at A is spacing, the line currents are in the same direction and tend to make its receiver mark. As the combined current is double that in the balance circuit, the receiver remains at mark.

109. At the B station, the line current is tending to make the receiver space, whilst the balance current tends to make it mark. Again, the line current is twice the size of the balance current, and thus the receiver changes to space.

Relayed circuits

110. In most telegraphs circuit, the receivers are not directly operated by the line signals. Instead, these signals are used to operate a relay which in turn operates the receiver.

111. Fig. 20 shows a switched simplex circuit modified for relay operation. It will be seen that the relay coils replace the receiver whilst the tongue changes the polarity of the receiver supply from the mark to space direction of flow, and vice versa, in accordance with the incoming signals.

112. This method of connecting the relay is used in all the circuits previously described.

Phantom circuits

113. D.C. telegraph signalling is normally carried out over conventional open-wire or cable routes, but a phantom circuit superimposed on a telephone circuit is sometimes used.

114. Fig. 21 shows the principle of phantom operation. A telegraph signalling current from C to D will divide between the two halves of the secondary winding of T1 as shown, thus inducing two opposing e.m.fs. in the primary.

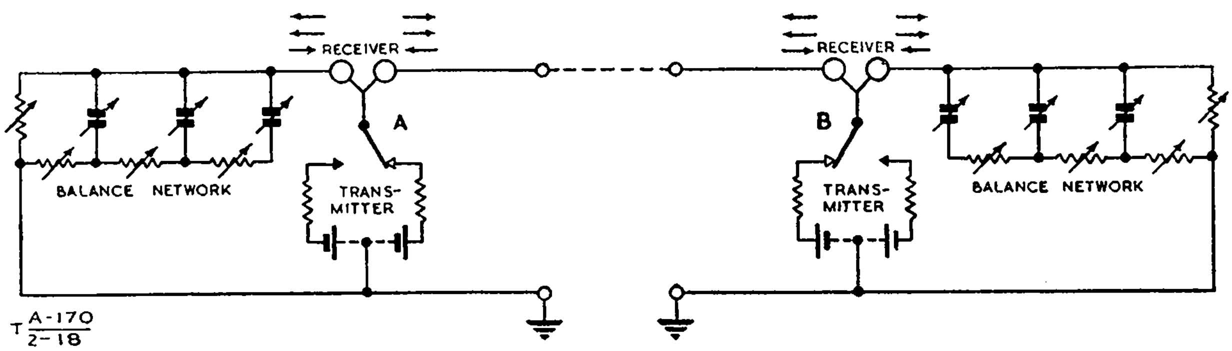

Fig. 18—Full duplex

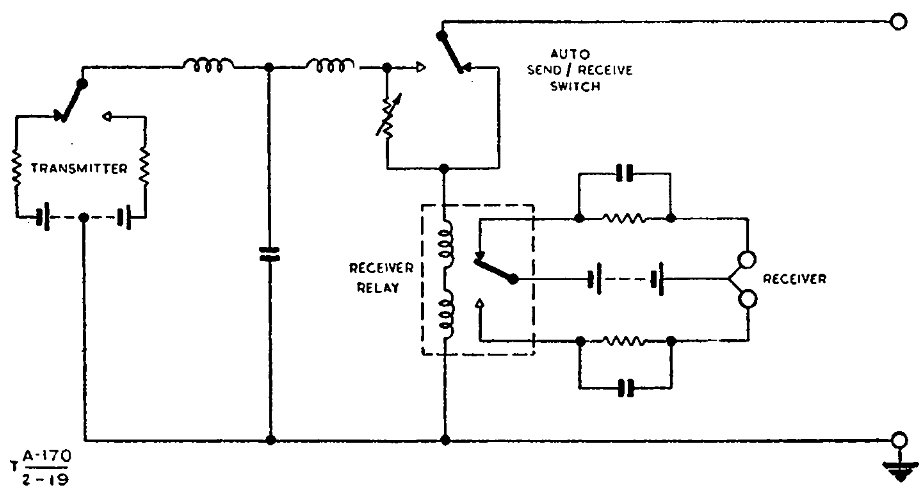

Fig. 19—Relayed switched simplex

115. If the two halves of the secondary are carefully balanced so that their impedances are equal, then the induced e.m.fs. will be of equal magnitude and opposite phase, thus cancelling out, and there will be no interference with the telephone circuit.

116. The action in T2, or when signalling from D to C, is similar, and the whole system may be used as a one-wire-with-earth-return circuit for simplex or duplex working. Where it is desired to use a 2-wire system, a 4-wire phantom, as shown in Fig. 22, is used.

Teleprinter switchboards

117. Prior to 1939, the normal method of routing telegraph messages between two points not directly connected by line was by manual retransmission, i.e., by retransmitting the message from intermediate points manually.

118. Such a method is slow and requires a considerable number of wires, which are a costly item, and manual switching has now been widely introduced. The switchboards used are similar in principle to a normal manual telephone switchboard, but calling, communication and monitoring are all carried out by teleprinter, no speech facility being provided.

119. Automatic switching is not at present employed for teleprinter working.

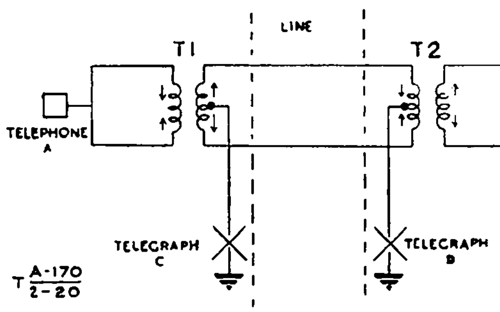

Fig. 20—2-wire phantom

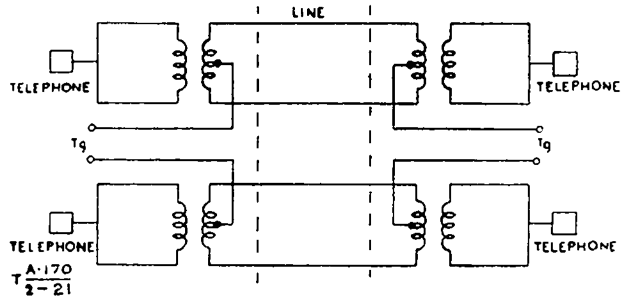

Fig. 21—4-wire phantom

NOTES ON TRANSMISSION LINES

●120. These notes are of a general nature and mathematical methods have been avoided where possible. Some of the arguments used are approximations and not strictly accurate under all circumstances, but the results are accurate and may be proved so by the use of more advanced mathematics. For a more complete or mathematical analysis of the factors involved, one of the standard text-books on the subject should be consulted.

121. Any transmission line may, from a theoretical point of view, be considered to be made up of a large number of sections similar to the one shown in Fig. 22. Each section consists of two conductors, A and B, having a total resistance, R, and inductance, L, joined by a leakage path consisting of the inter-conductor capacity C and a resistance, 1/G (G=conductance, hence 1/G=resistance).

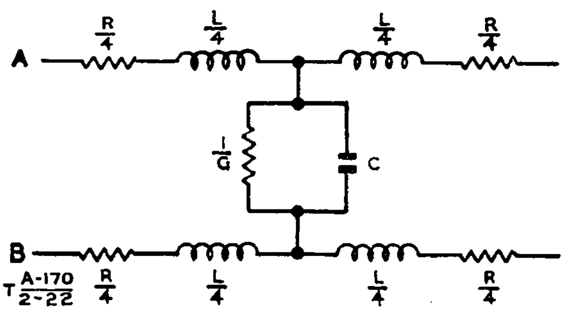

Fig. 22—Short length of transmission line

122. A complete line, with transmitter and receiver, may, therefore, be represented as in Fig. 23, Z_T and Z_R being the impedances of the transmitter and receiver respectively, and Z_1 and Z_2 the total series and leakage impedance of each section of the line.

123. A most important property of the transmission line network shown in Fig. 23 is that, except for short lines, the impedance it presents to the transmitter is practically a constant, independent of the length of line and the impedance of the receiver. Similarly, the impedance feeding the receiver is practically independent of the length of line and impedance of the transmitter. Even short lines have these properties if the transmitter and receiver impedances are approximately the same as that of the line.

124. This fixed impedance presented by a transmission line is termed its *characteristic impedance* and is usually denoted by the symbol Z_0 or Z_k.

125. A demonstration of the independence of Z_0 of the termination of the line, which also shows how its value can be determined, is given below. The actual equations are not important except to show a means by which the curve could be plotted.

126. The extreme values of receiver or transmitter impedance are infinity and zero, the former corresponding to a completely open-circuit condition and the latter to a short-circuit. In any practical case, the impedance will be between these values.

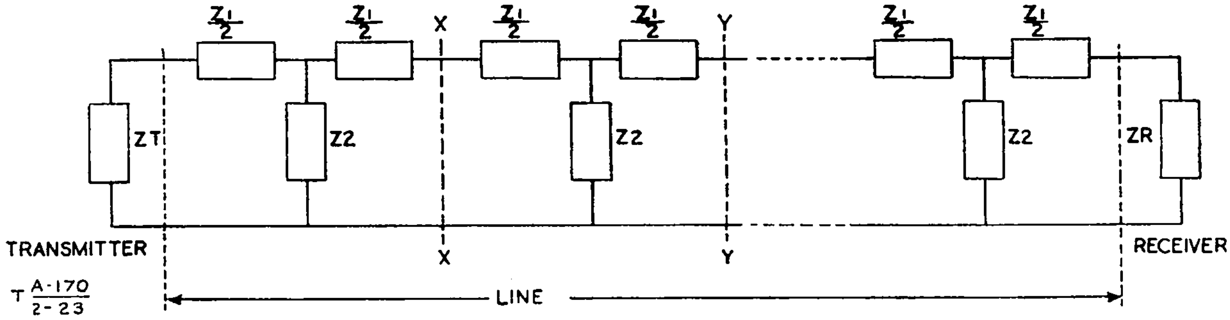

Fig. 23—Complete transmission line

127. Suppose we break the line in Fig. 23 at XX, one section from the transmitter, and leave the conductors open-circuited. The impedance presented to the transmitter is that of a single section.

$$Z_{x\ o.c.} = \frac{Z_1}{2} + Z_2$$

128. If we break it at YY, then the impedance will be that of two sections.

$$Z_{y\ o.c.} = \frac{Z_1}{2} + \frac{Z_2\left(\frac{Z_1}{2} + Z_{x\ o.c.}\right)}{\frac{Z_1}{2} + Z_2 + Z_{x\ o.c.}}$$

Similarly, we can derive equations for any number of sections and plot a graph of the results obtained.

129. The upper curve, $Z_{o.c.}$ in Fig. 24 was obtained in this manner, using typical practical values of Z_1 and Z_2 (only the magnitude of $Z_{o.c.}$ is represented, not its phase angle).

130. This curve represents the case of the infinite terminating impedance; for the case of zero terminating impedance, consider the ends of the section at which the line is broken to be short-circuited.

131. Assuming this condition, then the first two equations become

$$Z_{x\ s.c.} = \frac{Z_1}{2} + \frac{\frac{Z_1}{2} \times Z_2}{\frac{Z_1}{2} + Z_2}$$

$$Z_{y\ s.c.} = \frac{Z_1}{2} + \frac{Z_2\left(\frac{Z_1}{2} + Z_{x\ s.c.}\right)}{\frac{Z_1}{2} + Z_2 + Z_{x\ s.c.}}$$

This gives the lower curve, $Z_{s.c.}$ in Fig. 24 if the same practical values are used.

132. It will be noticed that the two curves $Z_{o.c.}$ and $Z_{s.c.}$ converge, although the line would have to be of infinite length for them actually to meet. The value of impedance at which they would meet is the characteristic impedance of the line.

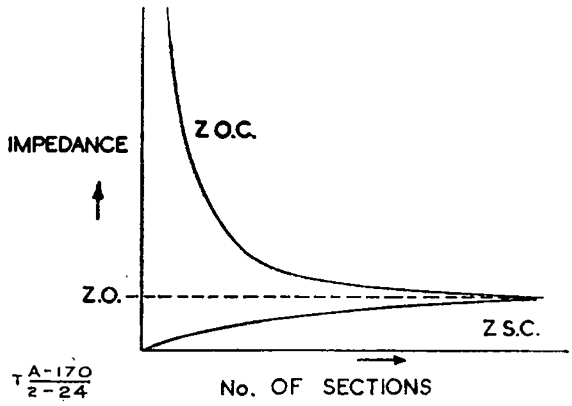

Fig. 24—Curves of $Z_{o.c.}$ and $Z_{s.c.}$ for a transmission line

●133. With any practical termination, the curve of impedance/number of sections lies between the limits shown. If the terminating impedance is equal to the characteristic impedance, the curve becomes the straight line shown dotted in Fig. 24, so that even for very short lines the impedance presented at the other end of the line is the characteristic impedance.

●134. The actual value of Z_o for any line can be determined practically by measuring the impedance of a portion of it, firstly with the ends short-circuited and then with them open-circuited. It can be shown mathematically that

$$Z_o = \sqrt{Z_{o.c.} \times Z_{s.c.}}$$

Line matching

135. One of the most important applications of the fixed value of line impedance is in ensuring the maximum transfer of power from transmitter to receiver.

136. It can be shown that when one network is feeding another (e.g., Z_G and Z_L in Fig. 25), the maximum transference of energy from one to the other takes place when their impedances are equal (e.g. when $Z_G = Z_L$).

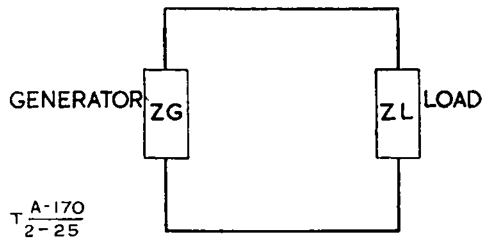

Fig. 25—Generator feeding a load

137. This consideration applies at two important points in a transmission line :—

(*a*) Where the transmitter feeds the line.

(*b*) Where the line feeds the receiver.

It follows, therefore, that to obtain a maximum of energy in the receiver the impedances of the transmitter, line, and receiver must all be equal.

138. Any one of these could be taken as a standard and the others varied to suit it, but the transmitter and receiver are normally designed to have the same impedance as the line. This process is known as line matching.

Variation of characteristic impedance

●139. It has been previously stated that the characteristic impedance of the line is given by

$$Z_o = \sqrt{Z_{o.c.} \times Z_{s.c.}}$$

$Z_{o.c.}$ and $Z_{s.c.}$ are not pure resistances and will be dependent upon the frequency of the voltage applied. It follows, therefore, that, although Z_o is a constant for a particular frequency, it does not actually have the same value at all frequencies. The extent of this variation will depend upon the particular line used, and it is one of the factors governing the frequency band which a line can pass.

140. The conditions in which a line is used may also affect its characteristic impedance. For example, a low-grade cable laid on the ground might show a variation of 25% above and below the mean, depending upon whether it was wet or dry.

Propagation constant

141. The fact that a line has a leakage path and also is inductive means that there will be loss of signal strength and distortion, the latter varying in amount with frequency.

●142. These two factors can be expressed in convenient form by quoting the propagation constant, γ, of the line. This coefficient is defined by

$$\frac{I_{in}}{I_{out}} = e^{n\gamma}$$

where γ = propagation coefficient per unit length
I_{in} = input current
I_{out} = output current
n = number of unit lengths
e = 2.718

The reason for choosing this form is discussed later.

143. To differentiate between the attenuation and distortion, two other constants are used :

$$\gamma = \alpha + j\beta$$

where

α = attenuation constant, which is a measure of the attenuation per unit length

β = wavelength or phase constant, which is a measure of the phase change

144. Consider the line shown in Fig. 26. The input current is I, and in the first section of the line it may flow by either of two routes

(*a*) Along the conductors

(*b*) Across the leakage path

The proportion going by each route will depend upon the ratio of the characteristic impedance of the line to the impedance of the leakage path. Suppose I_1 leaks away and I_2 passes along the conductor.

145. As I_2 reaches the second section it will similarly divide, and the current passing through will be reduced to I_4, the amount I_3 being lost. This will carry on all along the line; the further from the transmitter we place the receiver, the less will be the current available to operate it.

146. The impedance of the leakage path and of the line, if correctly matched, will be the same for all sections, hence

$$\frac{I_1}{I} = \frac{I_3}{I_2} = K$$

Thus the current is reduced by a constant proportion (K) at every section. At section 1 the amount lost will be KI, at section 2 it will be KI_2, at section 3 it will be KI_4, and so on. But the fact that the current itself is reduced in progressing along the line means that the current leaking away at any section decreases gradually.

●147. The actual value of current at any point in the line follows a curve similar to the one shown in Fig. 27. This curve follows a mathematical law of the form

$$\frac{I_{in}}{I_{out}} = e^k$$

It is for this reason that the definition of γ previously mentioned is employed.

148. So far only the reduction in signal level has been discussed. In fact, the inductance and capacitance of the line will also cause the phase angle of the current to be altered at each section, hence γ also includes a factor dealing with phase change.

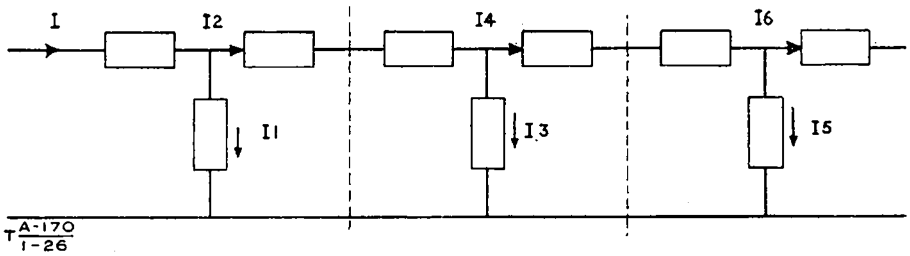

Fig. 26—Leakage in a transmission line

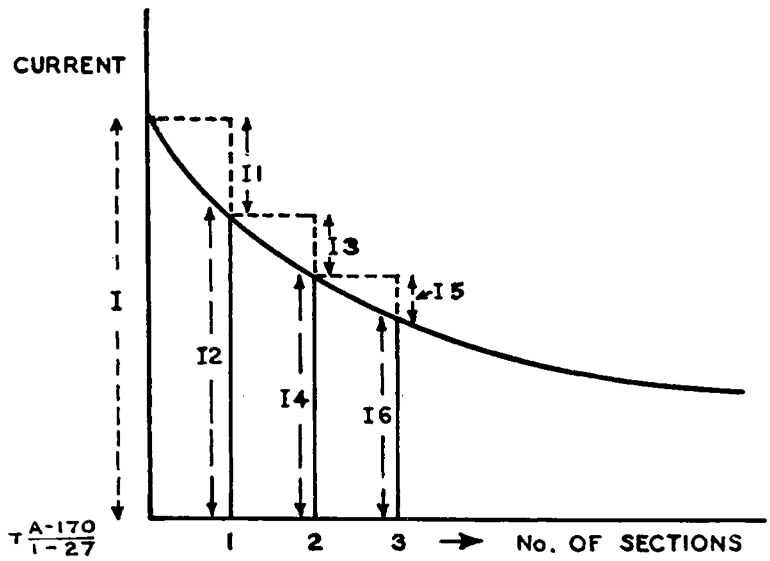

Fig. 27—Decay of current in a line

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