IMAGE EVALUATION TEST TARGET (MT-3)

1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2 3.6 4.0

6"

Cana

CIHM Microfiche Series (Monographs)

ICMH Collection de microfiches (monographies)

Technical and Bibliographic Notes / Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming, are checked below.

L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

- [ ] Coloured covers/ Couverture de couleur
- [ ] Covers damaged/ Couverture endommagée
- [ ] Covers restored and/or laminated/ Couverture restaurée et/ou pelliculée
- [ ] Cover title missing/ Le titre de couverture manque
- [ ] Coloured maps/ Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black)/ Encre de couleur (i.e. autre que bleue ou noire)
- [ ] Coloured plates and/or illustrations/ Planches et/ou illustrations en couleur
- [ ] Bound with other material/ Relié avec d'autres documents
- [ ] Tight binding may cause shadows or distortion along interior margin/ La reliure serrée peut causer de l'ombre ou de la distorsion le long de la marge intérieure
- [ ] Blank leaves added during restoration may appear within the text. Whenever possible, these have been omitted from filming/ Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.

- [ ] Coloured pages/ Pages de couleur
- [ ] Pages damaged/ Pages endommagées
- [ ] Pages restored and/or laminated/ Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed/ Pages décolorées, tachetées ou piquées
- [ ] Pages detached/ Pages détachées
- [x] Showthrough/ Transparence
- [ ] Quality of print varies/ Qualité inégale de l'impression
- [ ] Continuous pagination/ Pagination continue
- [ ] Includes index(es)/ Comprend un (des) index

Title on header taken from:/ Le titre de l'en-tête provient:

- [ ] Title page of issue/ Page de titre de la livraison
- [ ] Caption of issue/ Titre de départ de la livraison
- [ ] Masthead/ Générique (périodiques) de la livraison

- [ ] Additional comments:/ Commentaires supplémentaires:

This item is filmed at the reduction ratio checked below/
Ce document est filmé au taux de réduction indiqué ci-dessous.

10X	12X	14X	16X	18X	20X	22X	24X	26X	28X	30X	32X
										✓	

The copy filmed here has been reproduced thanks to the generosity of:

Library of the National
Archives of Canada

The images appearing here are the best quality possible considering the condition and legibility of the original copy and in keeping with the filming contract specifications.

Original copies in printed paper covers are filmed beginning with the front cover and ending on the last page with a printed or illustrated impression, or the back cover when appropriate. All other original copies are filmed beginning on the first page with a printed or illustrated impression, and ending on the last page with a printed or illustrated impression.

The last recorded frame on each microfiche shall contain the symbol —▶ (meaning "CONTINUED"), or the symbol ▼ (meaning "END"), whichever applies.

Maps, plates, charts, etc., may be filmed at different reduction ratios. Those too large to be entirely included in one exposure are filmed beginning in the upper left hand corner, left to right and top to bottom, as many frames as required. The following diagrams illustrate the method:

L'exemplaire filmé fut reproduit grâce à la générosité de:

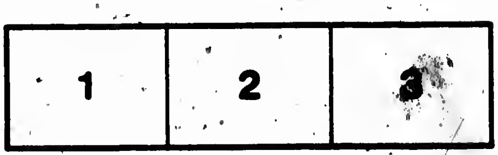
La bibliothèque des Archives
nationales du Canada

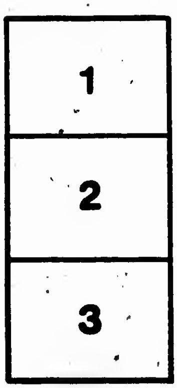
Les images suivantes ont été reproduites avec le plus grand soin, compte tenu de la condition et de la netteté de l'exemplaire filmé, et en conformité avec les conditions du contrat de filmage.

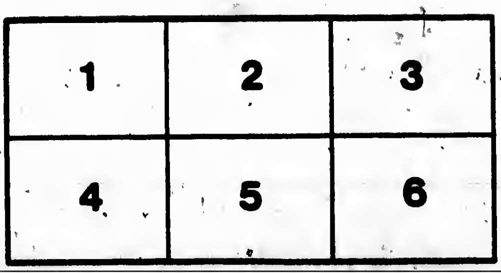
Les exemplaires originaux dont la couverture en papier est imprimée sont filmés en commençant par le premier plat et en terminant soit par la dernière page qui comporte une empreinte d'impression ou d'illustration, soit par le second plat, selon le cas. Tous les autres exemplaires originaux sont filmés en commençant par la première page qui comporte une empreinte d'impression ou d'illustration et en terminant par la dernière page qui comporte une telle empreinte.

Un des symboles suivants apparaîtra sur la dernière image de chaque microfiche, selon le cas: le symbole —▶ signifie "A SUIVRE", le symbole ▼ signifie "FIN".

Les cartes, planches, tableaux, etc., peuvent être filmés à des taux de réduction différents. Lorsque le document est trop grand pour être reproduit en un seul cliché, il est filmé à partir de l'angle supérieur gauche, de gauche à droite, et de haut en bas, en prenant le nombre d'images nécessaire. Les diagrammes suivants illustrent la méthode.







Canadian Society of Civil Engineers.

INCORPORATED 1887.

N.B.—This Society, as a body, does not hold itself responsible for the facts and opinions stated in any of its publications.

To be read on Thursday, 9th of October.

DEVELOPMENTS IN TELEGRAPHY: WAY-WIRES MULTIPLEXED AND INTERCHANGEABLE.

By D. H. Keeley, M. Can. Soc. C.E.

The title of this paper is so comprehensive that it might be supposed the writer purposed giving a *resumé* of all that has been attempted in the way of signalling since the word *telegraph* was first coined and found place in our vocabulary. It may be well therefore to state at the outset that it is only intended to deal with the subject of telegraphy in its present stage, introducing just enough of retrospect to show the drift, so far, of successful research in lines that, if followed up, will carry us to the realization of perfection in the art, and that is nothing short of the complete utilization, with the utmost economy, of the capacity of a line wire for the transmission of electrical effects.

Telegraph apparatus, and systems of telegraphy, have been so rapidly multiplied that scores of volumes and text-books are extant devoted exclusively to their treatment, either specifically or generally, and the student in wading through them finds difficulty in reconciling the idea of Advancement with the circumstance that, whereas indisputable and important properties of conductivity and electro-magnetism were early discovered, the Inventions from time to time introduced, instead of aiming to more and more fully utilise these properties, appear to have been designed to do in different ways just what had already been accomplished in the absence of a clear recognition of the possibilities attainable.

Supposing, however, for the sake of convenience, that two well-established facts—the celerity of conductivity and the diverse properties of electro-magnetism—were ever held in mind by the workers in this field, it will be possible to discriminate between the different systems that have been brought forward.

There are those, in that case, that have been designed to utilise the capacity of a line wire for the rapid transmission of electrical effects; they may be comprehensively designated *Simple Circuit Systems*. And there are those that have been designed to utilise the diverse properties of electro-magnetism, in which the use of auxiliary circuits is necessary; they may be described as *Complex Circuit Systems*.

With this division in mind it will occur to those conversant with the subject, that whatever progress has so far been made in the field of telegraphy is referable to the Complex Circuit Systems, comprehending the various methods for duplex and quadruplex transmission; while the obviously more far-reaching province of the Single Circuit, which embraces several automatic and synchronous systems, has been comparatively neglected, and, although extensively experimented in with splendid success, has never been developed in a measure to surpass the performance of its original arrangement constituting the ordinary Morse telegraph of forty years ago.

As this unique system, the Morse, is still universally in use, and a great deal depends upon its existence, it will be profitable to review it before proceeding further, for anything so old in the history of an art as this system is in telegraphy must have some remarkable features to recommend it.

Like the proverbial law that "holds good," the Morse has *nine points* that defies its dispossession of the field:—

1. The transmitter is a single contact key. The limit to speed is the physical possibility of an operator's manipulation, and the matter to be transmitted needs no special preparation.

2. The receiving instrument is simply an electro-magnet, the armature of which directly reproduces the movements of the transmitting key; and the immediate transcription of the operator is in proper shape for delivery.

3. The receiving instrument being electro-mechanical, an automatic repetition of transmitted signals from one circuit to another is readily obtained.

4. The circuit current is supplied from batteries at one or both of the terminal offices.

5. There may be any number of offices on a single wire, the only limit being the accommodation for traffic; and any number of the intermediate or way offices may be in or out of circuit without affecting the operation of the others.

6. The way offices are not called upon to contribute battery current to the main circuit.

7. The wire can be earthed at any point, thereby forming two separate circuits from earth to the respective terminal offices; each circuit being operative for all of the offices included in it.

8. At any way office one wire can be switched to connect with another, the equipment of the lines being uniform.

9. The last and very important feature is, that in the act of transmission, substitution of messages or interruptions by the receiving operator, or by any other in the circuit, can be effected instantly.

These are the *nine points* of advantage that distinguish the slow old Morse, and these are the advantages that render it as yet pre-eminent and indispensable.

There is no other system possessing all of these features, consequently there is none other equally advantageous. And it is clear that if the usefulness of a wire is to be enhanced, its equipment should have in its composition the means for affording in each separate line of communication the facilities of the single Morse circuit.

It is found, however, on examination, that this great desideratum has not been secured in any of the various methods that have heretofore been invented for the purpose of increasing the practical utility of the wire. [*It is important to bear this circumstance in mind in following this paper to its conclusion.*]

In reviewing the field of telegraphy it will be convenient to consider first the

SINGLE CIRCUIT SYSTEMS.

From time to time, dating from an early period in the history of our telegraphs, attempts have been made with more or less success to transmit signals by means of automatic *make* and *break* devices, perforated strips and the like, and to effect their reproduction by the action of the current impulses upon moving strips of chemically prepared paper. The speed attained has not unfrequently been marvellous and fairly incredible.

Without entering into a discussion of what may or may not have been the conditions of the circuits at times so successfully operated, it will suffice to state that the performance of these systems was not uniformly good and reliable.

Theoretically, any one of these systems would utilise the signalling capacity of a wire to its fullest extent. An almost inconceivably rapid succession of *makes* and *breaks* at the transmitting end of the line will produce a corresponding number of dots or dashes on the recording strip at the receiving end. And, since the current can effect chemical decomposition in a very much shorter time than it can produce the manifestation of magnetism, it is obvious that the same speed could not be attained by any arrangement of electro-magnets.

This will be understood in view of the fact, that a telegraph line 300 miles long is capable of transmitting about 1125 distinct electro-chemical effects per second. By an *effect* is meant the manifestation at the receiving end of the application or the withdrawal of current at the sending end. In a Morse operator's fastest manipulation (40 words per minute), there is produced but 24 electro-magnetic effects, or an equivalent of 12 dot signals per second.

At first sight, then, it would appear that an automatic system of the kind described, made reliable, would fill every requirement, and afford us in a single circuit the accommodation for which we are accustomed to employ a score or more of wires. Such is not the case in practice, however, and it is the discovery of its innate shortcomings and comparative inutility that has caused attention to drift away from the electro-chemical circuit.

The characteristic and maybe inseparable conditions most palpably disadvantageous to all of the automatic systems are that:

The matter to be telegraphed must be translated or specially prepared for transmission, and on its reception has to be retranslated for delivery. The collective preparation of a large amount of matter precludes the practicability of giving precedence to any single despatch or division. The signalling current [illegible] from the sending end [illegible]; consequently the corresponding offices must take turn about in [illegible], and there is no accommodation for way offices, unless [illegible] [illegible]

Besides these drawbacks to the automatic systems, there is the unavoidable nuisance of the paper tapes used at both the transmitting and receiving ends of the line. When the Morse system was developed to that stage where the single tape at the receiving end was dispensed with, a sigh of relief went up from every quarter where the business was of sufficient volume to produce an accumulation of the stuff in the course of a few hours work. The automatic in this respect is a retrograde system; in its working the paper tapes form the most important feature; the perforated and the marked material rapidly accumulates, and if fyled for purposes of reference it is difficult to get at any particular despatch, and no part of one can be so readily recognized as the easily fyled manuscript of despatches sent or received by the Morse system.

In fine, it has been found that the automatic systems cannot be advantageously operated, and the extreme rapidity of the chemical apparatus is, therefore, rendered practically unavailable.

The nearest approach that has been made to a realization of the expectations reasonably entertained of the electro-chemical systems is the performance of the Wheatstone Automatic. This system is a sort of compromise between the electro-chemical and the ordinary Morse. Its transmitter is essentially the same as those employed in the other automatic systems, while its receiver is electro-magnetic. The speed attained is of course much lower than that of the chemical apparatus, yet it is remarkably high compared with the work of a directly manipulated Morse circuit. It has already been stated, that in the operation of an electro-chemical system, 1125 effects can be produced per second, and of the Morse system, 24; with the Wheatstone system the rate attainable is as high as 386 electro-magnetic effects per second. In common with the other automatic systems, however, it has the already defined drawbacks rendering its general application impracticable.

Several printing systems have been brought forward but have not scored any great success. The chief defect in these is that the signalling medium is necessarily idle during the time that the mechanism operates to present successively the characters called for by the transmitter. With these therefore only a part of the signalling capacity of the wire is utilized, and a very high speed is obviously unattainable.

Another phase of single circuit operation is presented in the systems that have been devised to transfer the line wire from one apparatus to another successively at both ends of the circuit, and thus afford for each corresponding set an intermittent connection so rapidly recurring as to constitute a practically continuous one.

For a long time after the idea of these systems was suggested, it was considered impracticable, in consequence of the difficulty of obtaining the requisite perfect and continuous synchronous action of the machinery at either end of the line. In 1883, however, that difficulty was got over by the adaptation, in Mr. Delaney's synchronous multiplex, of the *phonic wheel*, a species of electro-motor; and more recently Lieut. Patton has succeeded in adapting an alternate current motor for the same purpose. (See the *Electrical World*, Vol. XIII, p. 106.)

Delaney's multiplex comprises the best features of all of the synchronous systems that preceded it. He has succeeded in getting with it six circuits suitable for the fastest Morse transmission. It is in operation on some lines in England and in the United States. The utility of this system, however, is limited in consequence of some very serious defects that will be specifically dealt with later on.

We now come to a consideration of the

COMPLEX CIRCUIT SYSTEMS.

The possibility of simultaneous transmission in opposite directions through a single wire was an early conception, but it was not until 1872 that the idea found practical application.

As soon as the principle became generally known and understood, the *Duplex*, as it is called, was introduced in multifarious forms. Its principle is a prolifically suggestive one. And in one form or other it is now found in operation wherever the traffic between any two stations is of considerable volume.

Of all the systems for duplex telegraphy that are in existence, however, there is but one—a somewhat recently introduced combination of telegraphic and telephonic apparatus—practically applicable to way stations. The reason for this is that the duplex depends for its operation upon devices for neutralizing the effect of outgoing currents in the receiving instruments, while leaving the latter free to respond to incoming currents. This necessitates the placing [illegible]

The *Quadruplex*—an arrangement of apparatus for double transmission in opposite directions,—first appeared in practicable shape in 1874. It is essentially an adaptation of the duplex principle; a combination, as it were, of two duplexes. There are, however, only four forms of the duplex susceptible of being so adapted. These are the Differential, Bridge, Split-battery, and Reciprocal (the last mentioned is described in the U. S. patent No. 331,975 granted to the writer conjointly with Mr. Aaron Garvey in 1885). For the exchange of business between centres where the wires are constantly occupied, the Quadruplex, in one or other of its forms, is now extensively used all the world over.

The general features of the quadruplex may be stated to consist in means for neutralizing the effect of the outgoing currents in the receiving instruments, and for effecting the production of signals on one side by increase and decrease of current, and on the other side by reversals of this current; or, as in the Reciprocal system, by currents of a given strength on the one side and heavier currents of the same polarity on the other side.

Attempts have frequently been made to apply these means for the production of a *sextuplex* system; but the greater necessity for special devices such as are used in the quadruplex to obviate interference of the effects of the current of one side with the other, involves so great an amount of complication and machinery as to render the idea impracticable.

The inherent defects of the several quadruplex systems consist in:—

1. The receiving instrument is in every instance dependent for its energization upon the battery at the transmitting station. This necessitates nice adjustment on the one hand and extraordinarily heavy currents on the other.

The fine adjustment of the receiving instrument exposes it to influence of induction from strong currents transmitted from the same end in wires running parallel to its circuit. And the heavy currents transmitted to effect the receiving instruments occasion the same mischievous induction effects in other circuits adjacent.

Owing to these conditions it is a matter of considerable difficulty to keep the apparatus in working order.

2. There is no means for including intermediate offices in circuit.

3. One receiving operator is unable to interrupt his correspondent without interrupting the other two operating on the same side. That is what occurs in each of the duplexes; each of which has four operators,—a sender and a receiver at each end. Hence, of 4 or 8 operators at work on one wire, three are handicapped if the fourth be inexpert; and it has thus become necessary to detail the best available operators for duty on duplex and quadruplex circuits.

With these facts before us we can readily understand the fairness of its being estimated, that the value of a duplex *circuit* is about 90 per cent., and a quadruplex circuit about 75 per cent, that of a simple Morse line between any two stations. In other words, a quadruplex is only about as good as three straight Morse circuits. And we can see, too, in the light of these facts, how very far those multiple circuit systems have fallen short of the advantages of the simple Morse circuit set forth in the beginning of this paper. At the same time, it will be remarked that the work done in respect of these systems has been one of steady development and extensive application in practice; they have been brought to that stage where all but their inherent defects are eliminated, and we perceive, in view of the already mentioned signalling capacity of a line wire, that the principles underlying them are not the correct ones on which an *ideal* system can be based.

THE SYSTEMS COMPARED.

To get as a clear idea now of the comparative value of the different systems, we can admit a *maximum* of efficiency in each case—crediting the quadruplex, for example, with the full value of 4 Morse circuits—and set down the highest rates of transmission quoted in works in which they are specifically treated. By classifying them as hereunto we can readily perceive how they stand.

		Rate Per Minute
Single Circuit—*Manipulated.*		
	Morse	40 words
	Type Writing (Hughes or Phelps)	50 "
	Synchronous Multiplex (6 circuits × 40 =)	240 "
Single Circuit—*Automatic.*		
	Electro-Chemical	1500 "
	Electro-Magnetic (Wheatstone)	428 "
Complex Circuit—*Manipulated.*		
	Duplex (2 × 40 =)	80 "
	Quadruplex (4 × 40 =)	160 "

Leaving aside the question of the practical availability of the electro-chemical method, we have seen that the value of its remarkably high speed is reduced by the necessity for dual translation of the matter transmitted; the same is true of the Wheatstone Automatic, the next highest in point of signalling capacity.

Of the systems operated by direct manipulation, the simple Morse is the only one of general utility. The others are, as has been pointed out, only adaptable to terminal stations; of these latter, however, the synchronous multiplex is shown to have the greatest efficiency. It is besides a simple circuit system and the nearest of any akin to the simple Morse.

The indications are therefore very clearly defined, that the principle upon which the synchronous multiplex is based is the correct one to follow up, with a view to the full utilization of the line wire.

We can now with advantage revert to a consideration of that principle, and in due course it will transpire how, by properly applying it, we can create a perfect system of

MULTIPLE CIRCUITS.

If a moment's consideration is given to the fact, that the signals transmitted by an operator on a Morse wire are made up of dots, dashes, and spaces, it will be perceived that there are in these several conditions certain periods of rest. When the key is open (spacing) for instance, the circuit is fulfilling no function. Can this period be taken advantage of, and the line wire for the time of its duration, however short, be transferred to complete a circuit with other sets of apparatus?

That is the question on which the operation of the synchronous multiplex hinged, and it has been answered affirmatively.

To get at an understanding of it, the action of the current upon the electro-magnet must be considered.

It is evident the magnetism developed in the iron core by the action of the current does not appear and disappear in its greatest strength abruptly; there must be a rise and a fall to it. Some time is taken for the magnetism to develop after the current is applied, and some time is taken for the magnetism to die away after the current is withdrawn. There is as it were a residual magnetism in the core for a brief period after the current is withdrawn. And it further appears that the stronger the current is the longer will the residual magnetism last. If the armature of the electro-magnet were arranged to respond to the effect of a weak current, and a strong current were applied, it is evident the armature would remain attracted for some time after the current was withdrawn; if the current were withheld for a brief space the armature would fall away; but if the current were re-applied very quickly, the electro-magnet would become re-energized before the armature would have had time to fall away. Hence, by alternately applying and withdrawing the current very rapidly, the electro-magnet would appear to be influenced by a continuous instead of an intermittent current.

Now, that being the case, it is evident that a number of points in a circle might be made the terminals of conductors leading to the electro-magnet, and a revolving arm successively touching these points might be the means of communicating the current to it. In that case it would only be necessary to apply the current to the arm in order to actuate the electro-magnet. And if between these several points another set of points is placed and put in connection with a second electro-magnet, this one would be actuated in like manner to the first, and so on, until the entire space of the circle were occupied and a considerable number of instruments could be actuated.

Now, if a similar arrangement of electro-magnets and contact points is placed at a distant station, and the revolving arms are synchronised and connected together by a line wire reaching from one to the other, the line wire becomes a practically permanent conductor common to all of the electro-magnets, and yet it is only in connection with the several pairs of them one at a time, so that signals might be exchanged between any two corresponding sets without any reference whatever to the others.

Whether this could be realised in practice, was what Mr. Delany and others before him sought to ascertain in the working of their respective systems. We have seen the outcome of it in the synchronous multiplex, and the result is very satisfactory. It is, however, not nearly so efficient as it was expected to prove.

In the *Electrical World*, Vol. II., No. 18, of Dec. 29, 1883, and Vol. VI., No. 20, of 14th Nov., 1885, will be found illustrated articles fully explanatory of the original system and its improvements. These articles can be consulted for details; it answers our present purpose to have quoted the following facts:—

1. The receiving instruments are actuated by currents emanating from the sending end alone. Hence the system is only applicable to terminal stations.

2. It is necessary to afford to each operator 34 contacts per second with the line wire, in order to enable him to transmit with the same facility as on an ordinary circuit. This is practically equivalent to 3 contacts, or 3 impulses of current per dot signal.

3. The operation is confined to lines not exceeding 100 miles in length.

With these facts before us we perceive that the synchronous multiplex, according to Mr. Delaney's invention, is deficient in two important respects; its application is limited, and it does not economically utilize the signalling capacity of the line wire.

We have not to go very far to ascertain the causes that produce these restrictions.

In several of the text-books the laws governing the transmission of currents are fully set forth. Take for instance the work of Geo. B. Prescott, 1885, Vol. I, wherein it is shown (see note) that the time required to actuate an electro-magnet is about directly proportional to the length of the conductor and inversely proportional to its conductivity. An actual experiment is cited, p. 395, whereby it was ascertained that on a No. 8 iron wire 300 miles long, a Hughes (polarized) electro-magnet was actuated in ·003= $\frac{1}{333}$ of a second; while for an unpolarised electro-magnet the time required is stated to be ·01 = $\frac{1}{100}$ of a second.

By calculation in accordance with these premises, it appears a length of 100 miles of No. 6 iron wire (the size generally used for multiple circuit lines) is capable of producing a signal in ·0022= $\frac{1}{454}$ of a second on a receiver, † such as is used in the Delaney system. Here are the figures:—

	No. 8		No. 6			
Lengths	300	:	100	} :: ·01	:	·0022 = $\frac{1}{454}$.
Resistances	12·92	:	8·54			

Now, on referring to the descriptive articles already mentioned, it is seen that Mr. Delaney's apparatus comprehends 7 circuits (six signalling, and one corrective of the synchronism) of 12 contacts each; in all (12×7=) 84 line contact points. These 84 line contacts are alternately disposed with an equal number of contact points connected to earth, which serve to partially discharge the line between the successive transmissions of current, so there is altogether 168 contact points or "plates," as they are generally called, in the circle traversed by the line brush.

Suppose the parts to be of the following demensions:—

	Inches	Total
Line plates, each	$\frac{1}{4}$ = .25 in. × 84 = 21.0	
Earth " "	$\frac{1}{4}$ = .25 " × 84 = 21.0	
Spaces between ditto	$\frac{1}{40}$ =.025 " × 168 = 4.2	= 46.2

The circumference of the circle is in this case 46.2 inches, and as it is traversed by the line brush 2[illegible] times in a second, it follows that a distance of (46.2 × 2.83 =) 130.75 inches per second is covered.

Now, as the length of time occupied by the brush in passing over a given line plate is the exact measure of the duration of contact made with the battery, for the transmission of a current, it is evident that (since 130.75 : ·25 :: 1 : ·0019) the current is in each instance presented to line for only (·0019=) $\frac{1}{526}$ of a second.

Again, it will have been noticed in following these calculations, that with a given speed of rotation of the line brush, the width of the plates determines the length of time the current is put to line. This being the case, it is obvious that when the brush is passing over an earth plate, the line is fulfilling no function, it is idly discharging; consequently, with this arrangement the line is half of the time idle and its theoretical capacity is utilized to the extent of less than 50 per cent., the insulation wedges between the line and earth plates occasioning the slightly further loss.

That this disadvantage is inseparable from the system is evident, for the discharge of a line is always slower than the charge, and it is necessary in this system to obviate the possibility of an appreciable part of the charge due to the transmission of a signal between one pair of corresponding plates being communicated to the electro-magnets connected with the next succeeding pair.

† As the Hughes' apparatus already mentioned is not adaptable for general signalling purposes, and the polarised instruments in use, such as the Siemens relay, have practically about the same celerity of action as an unpolarised electro-magnet, the time required to produce a signal on an unpolarised magnet on the 300 mile line, viz., ·01 sec., is obviously, for purpose of comparison, the proper quantity to consider.

There is in the foregoing figures, too, an explanation of the other deficiency of the system. The apparatus in operation transmits currents of only .0019 sec. duration; we have seen elsewhere that the time required to produce a signal (that is, to effect a full attraction and movement of the armature of the receiving instrument) on a line of 100 miles of No. 6 iron wire is, by calculation, .0022 sec. The difference is so small that the figures may be said to agree. However, it is evident the transmitted current is barely sufficient to produce an effect; and, as the length of time required to produce a signal increases with the length of the conductor, it can be readily understood why the operation of the system is confined to comparatively very short circuits.

With the synchronous multiplex before us, its deficiencies discovered, and the causes thereof traced to an arithmetical certainty, it is an easy matter to define what the requisites are to produce an *ideal* system:—

1. The receiving instruments should be made responsive to single pulsations of an ordinary strength of current, so as to be independent of intermittances. This would economize the signalling capacity of the line.

2. The necessity for discharging the line after each pulsation should as far as possible be eliminated, so as to admit of minimising the earth-plates and thus afford space for additional line plates. This would secure the furthest utilization of the signalling capacity of the line.

3. The system should be applicable to intermediate stations. This would render every one of the several circuits as readily available and generally adaptable as a single Morse line.

Now, the attainment of this perfection is not only possible, it is the next thing to an accomplished fact, as will be seen in considering the results of the writer's personal research in this particular department. These results are comprised in a new system comprehensively designated,

THE INTERCHANGEABLE WAY-WIRE MULTIPLEX.

As this system is somewhat different from its predecessors in the principle of its operation, it may be best introduced for consideration by a general statement of its characteristics.

The conception of it is based like the other synchronous systems on the well-known fact that the manipulation of a key by the most expert Morse operator is very slow compared with the rapidity with which an electrical effect can be produced, and further, on the ascertained fact that when signals are produced by pulsations of alternate polarity, + closing and — opening, 24 *contacts per second* (12 corresponding to downward movements or depressions, and 12 corresponding to uprisals of the key) is all that is necessary for transmission at the rate of 40 words per minute.

According to this latter finding it is only necessary to make connection between any two corresponding sets of apparatus once in every $\frac{1}{24}$ of a second, in order to intercept every movement of a given key, and so produce precisely the same effect in the distant receiver as would obtain were the sending and receiving instruments continuously in circuit.

In order that this may be understood, the tape of a Morse register may be taken in an instance where signals have been embossed upon it at the rate of 40 words per minute. The length of a dot will be found to be $\frac{1}{24}$ of the length of tape passed over per second. Or, a sentence of 40 words may be written down in Morse characters on paper ruled with horizontal lines representing unit divisions, allowing 1 unit for a dot, 1 unit for the space between the elements of a letter, 3 units for a dash, 2 units for the space between letters, and 4 units for the space between words; it will be found that the entire sentence occupies 1440 divisions = 24 units per second, thus showing that $\frac{1}{24}$ *sec. is occupied in the formation of a dot or a space* in manipulation at the rate of 40 words per minute.

On the other hand, it is known that the time required for the production of a signal by electro-magnetism is extremely brief; only ·003 = [illegible] of a second, with sufficiently sensitive yet practical apparatus, on an ordinary No. 8 iron telegraph wire 300 miles long, and in less time on a line of shorter length.

It is therefore obvious that the whole period ($\frac{1}{24}$ sec.) of each of 24 contacts that can be afforded in a second is not necessarily at the disposal of one operator.

Hence, if in every $\frac{1}{24}$ of a second the line wire is put in connection with a given key sufficiently long to produce one electrical effect, the balance of each $\frac{1}{24}$ of a second can be occupied in the production of electrical effects under other keys with which it can be successively connected. From this it follows that if the time required to produce an effect on a 300 mile line is only [illegible] of a second, we can, theoretically, obtain in it as many as ([illegible] =) 12 signalling circuits.

Now, it will have been seen in the description thus far, that the principal action hinges on the possibility of the brief transmitted current affecting the receiver, in such a way as to leave an impression upon it during the interval of the succeeding pulsations. That is, if a + pulsation is transmitted in the formation of a dot or dash, the armature of the receiver must be attracted and remain so until a — pulsation, transmitted in the formation of a space, reverses its position.

And it is also evident that the receiver must be extremely sensitive in order to afford the maximum number of signalling circuits on a given line.

To see how this is provided for, it will be remembered that in dealing with the other systems just now, it was shown that a signal can be produced on a Hughes' magnet in $\frac{1}{312}$ sec. against $\frac{1}{107}$ sec. required for electro-magnets of other forms. In other words, the Hughes is 3 times quicker in its action.

Now, it has been found in the course of experiments made with reference to this system, that if an ordinary polarised relay is operated through the medium of an induction coil, the relay is rendered responsible to a single brief pulsation of current; whereas, when operated directly, three successive pulsations are required to produce a full attraction of its armature. That is to say, the combination with the induction coil furnishes a receiving instrument equal in celerity with the Hughes magnet, and should therefore be capable of response to a signalling current of $\frac{1}{312}$ sec. duration on a 300 mile line of No. 8 iron wire. By means of an automatic device, the induced currents communicated to the relay operate in only one direction dependent upon the polarity of the transmitted pulsation. Consequently its armature remains at rest against one or other of its limiting stops, according to the direction of the last current presented to it, and is unaffected by successive pulsations of the same polarity.

Now, having an economical method of signalling and the requisite apparatus therefor, it is only necessary to associate it with means for transferring the line wire from one set of instruments to another simultaneously, at as many stations as desirable on a line, in order to produce a multiplicity of signalling circuits.

In the references that have already been mentioned in connection with previous systems (viz., *Electrical World*, Vols. II, VI and XIII), the means whereby synchronism can be obtained and maintained between stations connected together in circuit is set forth in a sufficiently clear manner, to obviate the necessity for explaining in detail the specific arrangements that have been devised for that purpose in this instance. It will suffice to state here that motors at the terminal stations of a line are brought into unison by correcting devices. Currents regularly alternating in polarity are concurrently transmitted to line from both terminals; these currents conjointly operate the motors at the intermediate stations, and the result is a perfectly synchronous action throughout the entire system.

By means of this synchronous mechanism, a brush in electrical connection with the main line is revolved about the circle of contacts connected with the signalling apparatus, at all of the stations in circuit, with sufficient frequency to put the line in contact with each of the corresponding sets of apparatus once in every 1-24 of a second; and at each of the terminal stations the shaft that revolves the brush carries a commutator of a sufficient number of segments to produce 24 reversals per second of the main line battery which is connected with it.

The main batteries at the terminal stations are moreover reversely connected with the commutators, consequently + presented to line at one end is met by — presented at the other end; the currents combine in the line, and, as they are alternated by the revolving commutators, the line is traversed by regularly recurring + and — pulsations.

It will be seen, therefore, that the passage of the main line brush over the contact plates connected with the signalling instruments is concurrent with the presentation to line of any one phase + or — of the main line current. Hence, if the contact plates are arranged in series equi-distantly, and corresponding to the segments of the commutator, certain of the contacts will regularly and invariably afford a path for the +, and the others for the — pulsations.

And, further, if the transmitting keys are provided with front and back contacts, respectively connected with the + and — series of the line plates, the levers of the keys being connected with the battery commutator, it is evident that when any given key is depressed or upraised it will, in its circuit, interrupt the path of one or other of the currents.

This being the case, the polarity of the current transmitted depends upon the position of the key in the case of each of the signalling circuits.

Now, as the + and — phases of current are presented in each instance for $\frac{1}{12}$ of a second, during which time the line brush traverses one entire series of the contacts, it is clear that if the keys in some of the circuits were depressed and in others upraised, the current would be interrupted and re-established repeatedly, so that it becomes broken up in a succession of mere pulsations. The fact is, therefore, that each of the signalling circuits is operated by means of a single pulsation that recurs alternately + and —, every $\frac{1}{24}$ of a second, and the position of the key determines whether a given pulsation shall or shall not affect the receiving instruments that are in circuit with it.

It might appear at first sight that there is a chance of a movement of the key taking place between two successive pulsations, that would not be reproduced in the receiver; but a moment's consideration will show this to be impossible, since every movement of the key by the operator's hand occupies, at the very least, a period of time that is sufficient for the line brush to sweep over the entire series of the circuits. There is, however, this possibility, that in a case where + currents operate to close the receivers, and — currents to open them, the sending key might be depressed concurrently with the presentation of a — phase of the current, and upraised concurrently with the succeeding + phase. In such a case it is evident the movement of the key would be lost on the receiver; this possibility is, however, obviated by means of a semi-automatic transmitter through which the movements of the key are communicated to the line circuit. The operation is simply this: If the key is depressed to form a dot, the lever of an electro-magnet, in local circuit with the key, is depressed, and remains in that position, after the key is upraised, until a + pulsation transmitted to line releases it. The lever in its upraised position affords a path for the succeeding — pulsation. A dot is thus transmitted. If the key is again depressed, the same operation is repeated; so long as the key remains open only — currents go to line; and when closed, + currents are transmitted. As the successive pulsations recur with the same rapidity as the movements of the key, it is obvious the latter cannot get ahead of the former; consequently, every movement of the key is reproduced in the receiver, the operation being precisely the same as if the key moved in exact unison with the recurring alternations of current.

There now remains only one other important feature to point out: It is, that as in this system the receiving apparatus is positive in action and responsive to one full pulsation of either polarity, it is not in any given circuit susceptible to the influence of the tailings of the charge in the line due to the transmission of a signal in the circuit immediately preceding. It is therefore sufficient to put between the successive line plates a very narrow segment for earth contact. Between the separate series an earth plate, as large as any one of the line plates, is provided to fairly clear the line of the charge of one polarity before the other is introduced.

Reverting for a moment to the explanation given as to how signals are transmitted, it will be remembered that the current pulsations are regularly presented, and it is the position of the keys that determines their circulation in the respective circuits. It will therefore be readily understood how intermediate offices can be introduced on the line; they have circles of line contact plates and the rest of the apparatus; the transmitted currents pass through them, each circuit having its own pulsations to which the receivers respond. As at the terminal stations so is it at the way offices, the position of a given key determines the circulation of the current. Normally, all of the keys in a given circuit are closed, and the recurring + and — pulsations circulate in it. The opening of any one key, therefore, will affect all of the receivers in the circuit, and they will follow its movements precisely as on an ordinary single-circuit Morse wire.

The interchangeable feature of the system is also almost self-evident. Since the signalling currents emanate from both ends of the line, any one of the intermediate offices can ground a given circuit and work in either direction independently; or loop lines can be introduced and operated precisely in the same way as when let into a regular Morse circuit; or a number of offices may be regularly on one circuit while a certain other number may be on another, and these can interchange in the same way as if located on so many separate wires. Moreover, we have this very desirable feature, that in the normal condition the keys being all closed, the apparatus at an intermediate office presents no obstruction whatever to the passage of the currents; it may therefore be out of adjustment or otherwise disarranged without affecting the other offices in circuit, just as on an ordinary Morse line which, is operative between offices whose instruments are adjusted and inoperative to those whose instruments are not adjusted or otherwise locally affected.

Now, from what has been stated, it is evident that we have here a system calculated to afford the highest possible degree of efficiency and one that utilizes the capacity of the line wire to the fullest extent.

Of 13 circuits theoretically obtainable in a wire 300 miles long, we can count upon at least 9 for signalling purposes; we might do more than that, but recollecting that the number depends upon the length of the surface traversed by the line brush per second, the space equivalent to 4 circuit plates is only a liberal allowance to make for the synchronous circuit plate, the earth plate, and its minor segments and the insulation wedges. All these may be taken together and set down as *mechanical intervention*, and therefore a constant quantity; and in any calculation we make for a given line, we may subtract the equivalent of 4 circuits from the theoretical in order to determine its practical capacity. Thus, in accordance with the law of proportions elsewhere dealt with in this paper, we should obtain on an ordinary line 150 miles long, as + many as ($\frac{300}{150}$ × 13 = 26, — 4 =) 22 signalling circuits. It now only remains to be seen whether this can be realized in practice.

(REFERENCE SHEET 35.)

Note.—It is not stated so, literally, but it is in effect: It is stated on p. 397, that "The rapidity with which successive signals can be transmitted depends essentially upon the time required to charge and discharge the line." This time, it is shown on p. 393, is on a No. 8 iron wire 300 miles long, about ·018 sec., and on an equal length of No. 6 gauge (·20 in diameter), the time required is about ·013 sec.

It is stated on p. 395, that the time required to produce an effect on the No. 8 wire was found to be with a Hughes electro-magnet ·003 sec.: and ·01 sec. is set down for an unpolarized electro-magnet of the ordinary form.

It further appears, on p. 395, that on a given line with one class of apparatus, the time required to produce an effect is "nearly in proportion to the length of the line;" and with the other class of apparatus the time required "increases in a much greater proportion than the length of the line." These statements have reference to lines of 300 miles and over, and it is therefore very safe to assume that for lines under 300 miles the time is at the most directly proportional to the length.

The obvious interpretation of all this is, that the time required to charge a line is the index of its signalling capacity. If we know the rate of charge of any two wires and the signalling capacity of one of them, we can, by a simple sum in proportion, determine the signalling capacity of the other.

According to these figures and statements then the time required to produce an effect on an unpolarized magnet on the 300 mile No. 6 line is ·0072 sec.; the proportion being ·018 : ·013 : : ·01 : ·0072. And the time required on a 100 mile length of the same line is ·0024 sec.; the proportion being ·300 : ·100 : : ·0072 : ·0024.

The result is practically the same as that arrived at by the other calculation. Besides, that interpretation of the text is supported by the statement, *Prescott*, Vol. II, p. 1110, that "the speed (having reference to the synchronous multiplex) is inversely proportional to the length and directly as the size of the conducting wire."