one in each direction, over the same wire. The solution of this problem was attempted by Gintl of Vienna in 1853 and in the following year by Frischen and by Siemens and Halske. Within a few years several methods had been proposed by different inventors, but none were at first very successful, not from any fault in the principle, but because the effect of electrostatic capacity of the line was left out of account in the early arrangements. The first to introduce a really good practical system of duplex telegraphy, in which this difficulty was sufficiently overcome for land line purposes, was J. B. Stearns of Boston (Mass.). In order that the line between two stations S1 and S2 may be worked on the duplex system it is essential that the receiving instrument at S1 shall not be acted on by the currents sent into the line at S1, and similarly that the currents sent into the line at S2 shall not act on the receiving instrument at S2, while at the same time these currents must act on the instruments at S2 and Sl respectively. The two methods most commonly employed are the following.

1. In fig. 26 B is the sending battery, B1 a resistance equal to that of the battery, R a set of resistance coils, and C a condenser. Suppose the key at station S1 to be de­pressed ; then a cur­rent flows into the line through cir­cuit 1, and to earth through circuit 2. Now, if both these currents pass, as in­dicated in the fig­ure, round the elec­tromagnet of the receiving instru­ment, but in opposite directions, and if their strengths are pro­perly adjusted, no effect will be produced on that instrument. At station S2, however, the current flows to earth, partly through cir­cuit 1 and partly through circuit 2, but in the same direction round the coils of the receiving instrument. Hence, if the current is strong enough, the receiving instrument at S2 will be set in action. Similarly the depression of the key at S2 can be made to produce a signal at S1 and yet have no effect on the instrument at S2. The necessary and sufficient condition is that the currents in circuits 1 and 2 at the sending station shall at all times bear a certain fixed ratio to each other, depending on the coils of the receiving instrument at that station. If for simplicity we suppose the resist­ance of the line to be constant and not to be affected by the trans­mitting apparatus, and to be of zero electrostatic capacity, the fixed ratio may be obtained by adjusting R in the auxiliary circuit 2. In actual practice the line has capacity, and this is com­pensated for by supplying to R from the condenser C capacity equivalent to that of the line. C should be of such a form that the capacity in the circuit can be varied, and it must have the same inductive retardation as the line ; that is to say, the capa­city must be distributed along the resistance R in a manner equi­valent to that in w’hich the capacity of the line is distributed along its resistance. A rough approximation to this adjustment will answer the purpose for ordinary land line working, but for submarine cable work a very accurate adjustment is necessary. In order that the manipulation of the key may not affect the resist­ance of the line, the resistance between the point D and E should be as nearly as possible the same for all positions of the key. This implies that the keys shall not at any time break circuit, nor make contact on both the front and the back stops for more than an instant, for an instantaneous break of the circuit would affect the signals being received from the other station. The principle of the “continuity preserving key,” used for duplex working, will be understood from the figure. So long as the key is not depressed the line is kept to earth through the resistance B1 ; when the key is pushed down it suddenly changes to the battery B, being at the transition in contact with both B and B1. This produces very little disturbance, because the key is moving quickly at that part of its stroke, and the resistance of the line and receiving instru­ment is generally much higher than that of B1. This is called the “differential method.” The principle was first enunciated by Frischen ; but its present condition is the result of the labours of a large number of experimenters, among whom may be mentioned Siemens and Halske, Stark, Edlund, Gintl, Nyström, Preece, Nedden, Farmer, Maron, Winter, Stearns, and Muirhead.
2. The second method to which we may here refer is known as the “bridge method” from the similarity of the arrangement (see fig. 27) to that of the Wheatstone bridge. Instead of sending the currents in the two branches of the divided circuit DP and DQ through the two coils of a differentially wound relay or receiving instrument, as in Frischen’s method, two resistances *a* and *b* are inserted and the instruments are joined between P and Q. It is clear that if the difference of potential between P and Q is unaffected by closing the sending key K no change of current will take place in the instrument circuit. The relative potential of P and Q is not affected by the manipulation of K if the resistance *a* is to that of *b* as the resistance of L is to that of R ; hence that is the arrange­ment used. The same remarks w’ith regard to retardation and capacity that were made when describing the differential method apply here also. One very great advantage in this method is that the instrument used between P and Q may be of any ordinary form.

Most important cables, such as those of the Eastern Telegraph Company and the various Atlantic cables, are worked duplex on Muirhead’s plan. What may be called a mechanical method of duplexing a cable was described by Sir W. Thomson in a patent taken out by him in 1858. In this, as in the ordinary methods, a differentially wound receiving instrument was used, one coil being connected with the cable and the other with the earth ; but it differed from other methods in requiring no “artificial” or model cable. The compensation was to be obtained by working the slides of a resistance slide included in the circuit of the compensating coil, either by the sending key or by clockwork relieved by the key, so as to vary the resistance in that circuit according to any law which might be required to prevent the receiving instrument being affected by the outgoing current. Four years later Varley patented his model cable, which was the first near approach to a successful solution of the duplex problem on the principle now adopted. It was not, however, a sufficiently perfect representation of a laid cable to serve for duplexing cables of more than a few hundred miles in length.@@1

By an interesting modification of the bridge method, which has been applied with excellent results by Dr Muirhead to submarine work, condensers are substituted for *a* and δ, one being also placed in the circuit between P and Q. In this case no current flows from the battery through the line or instruments, the whole action being inductive. As we have already stated, the distribution of the capacity along the resistance R must in submarine cable work be made to correspond very accurately with the distribution of the capacity along the resistance of the cable. This is accomplished by Dr Muirhead in the following manner. One side of a sheet of paraffined paper is covered with a sheet of conducting substance, say tinfoil, and over the other side narrow strips of the same sub­stance are arranged gridironwise to form a continuous circuit along the strip. The breadth and thickness of the strip and the thick­ness of the paraffined paper are adjusted so that the relative resist­ance and capacity of this arrangement are the same as those of the cable with which it is intended to be used. A large number of such sheets are prepared and placed together, one over the other, the end of the strip of the first sheet being connected with the beginning of the strip of the second, and so on to the last sheet, the whole representing the conductor of the cable. In the same way all the conducting sheets on the other side of the paper are connected together and form the earth-plate of this artificial cable, thus representing the sea. The leakage through the insulator of the cable is compensated for by connecting high resistances be­tween different points of the strip conductor and the earth coating. Faults or any other irregularity in the cable may be represented by putting resistances of the proper kind into the artificial line. This system of duplexing cables has proved remarkably successful.

Quadruplex telegraphy consists in the simultaneous transmission of two messages from each end of the line. The only new problem introduced is the simultaneous transmission of two messages in the same direction ; this is sometimes called “ diplex transmission.” The solution of this problem was attempted by Dr J. B. Stark of Vienna in 1855, and during the next ten years it was worked at by Bosscha, Kramer, Maron, Schaak, Schreder, Wartmann, and others. The first to attain success was Edison, and his method with some modifications is still used. One of the latest arrangements is shown in fig. 28, a brief description of which will indicate the general principle involved. K1 and K2 are two transmitting keys the nature of which will be understood from the illustration ; R1 and R2 are two differentially wound polarized relays, both of which are supposed to respond to positive currents and to be held against their back-stops by negative currents. When neither key is de­pressed a current, which for convenience we call - 4, flows to the line ; this is sufficient to overcome the pull of the spring T in the relay R1 (the receiving instruments are supposed to be at the other end of the line), and hence the levers of both relays are held against their back-stops. When K1 is depressed a current -1 is sent to the line, and, this being too weak to overcome the spring T, the lever

@@@1 See De Sauty, *Journ. Soc. Tel. Eng.,* vol. ii., 1873.