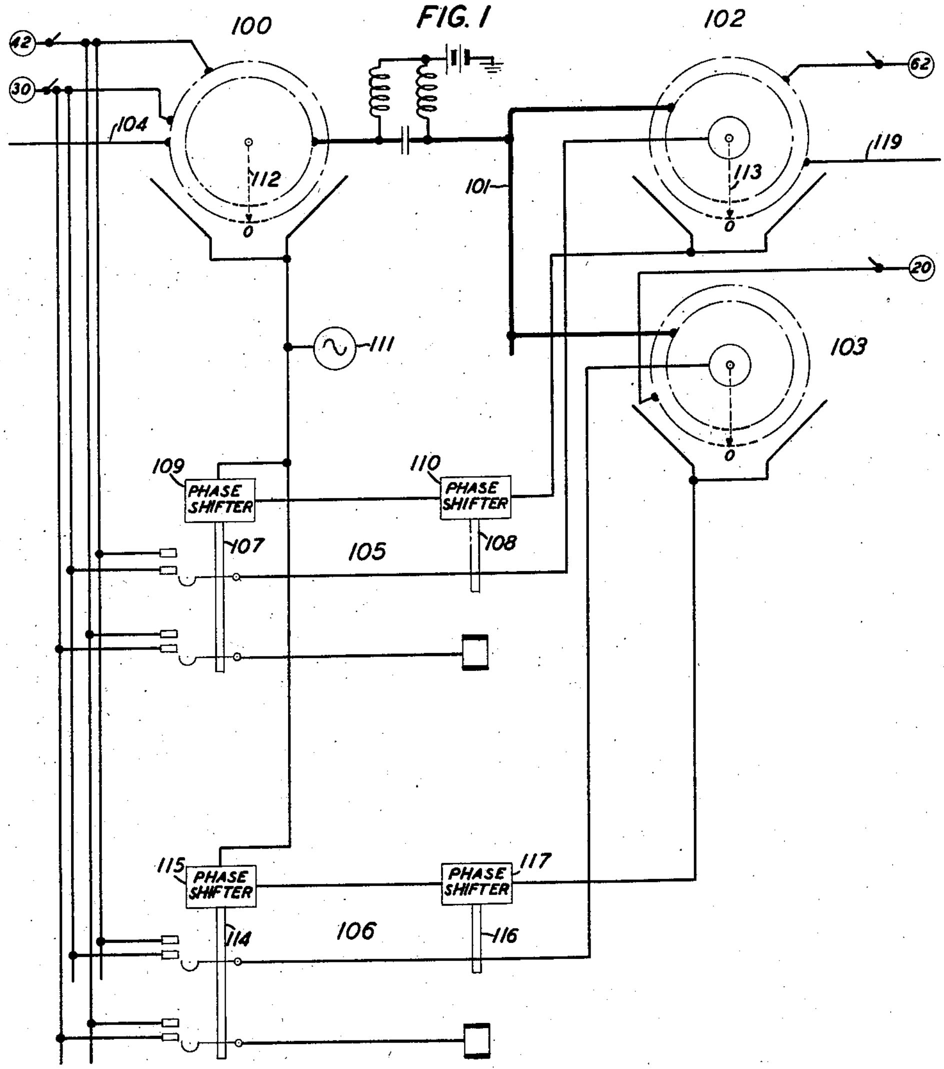
FIG. 1



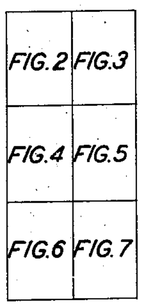


FIG. 9

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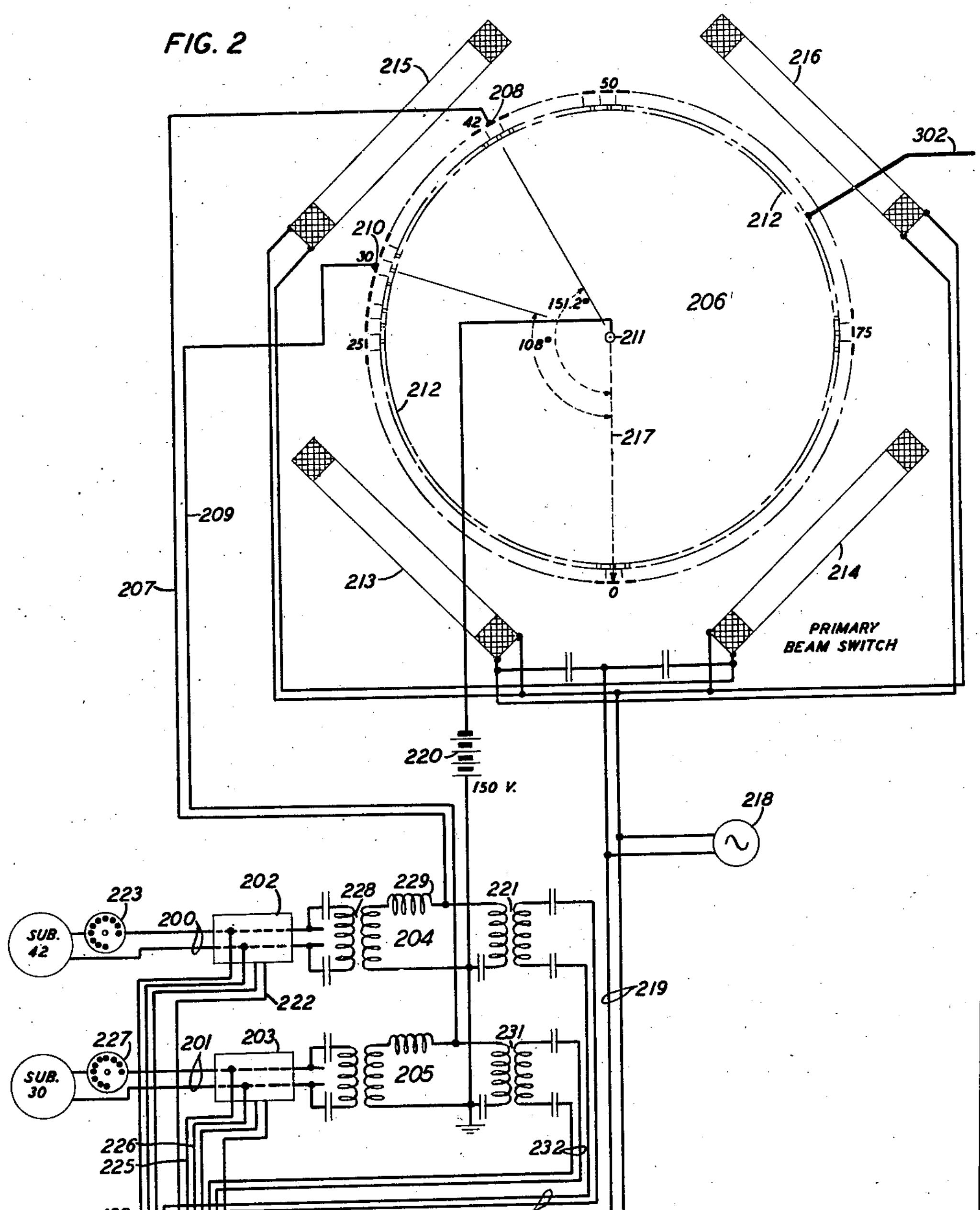
COMMUNICATION SYSTEM

Filed Oct. 9, 1942 7 Sheets-Sheet 2

FIG. 2



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Filed Oct. 9, 1942 7 Sheets-Sheet 3

FIG. 3

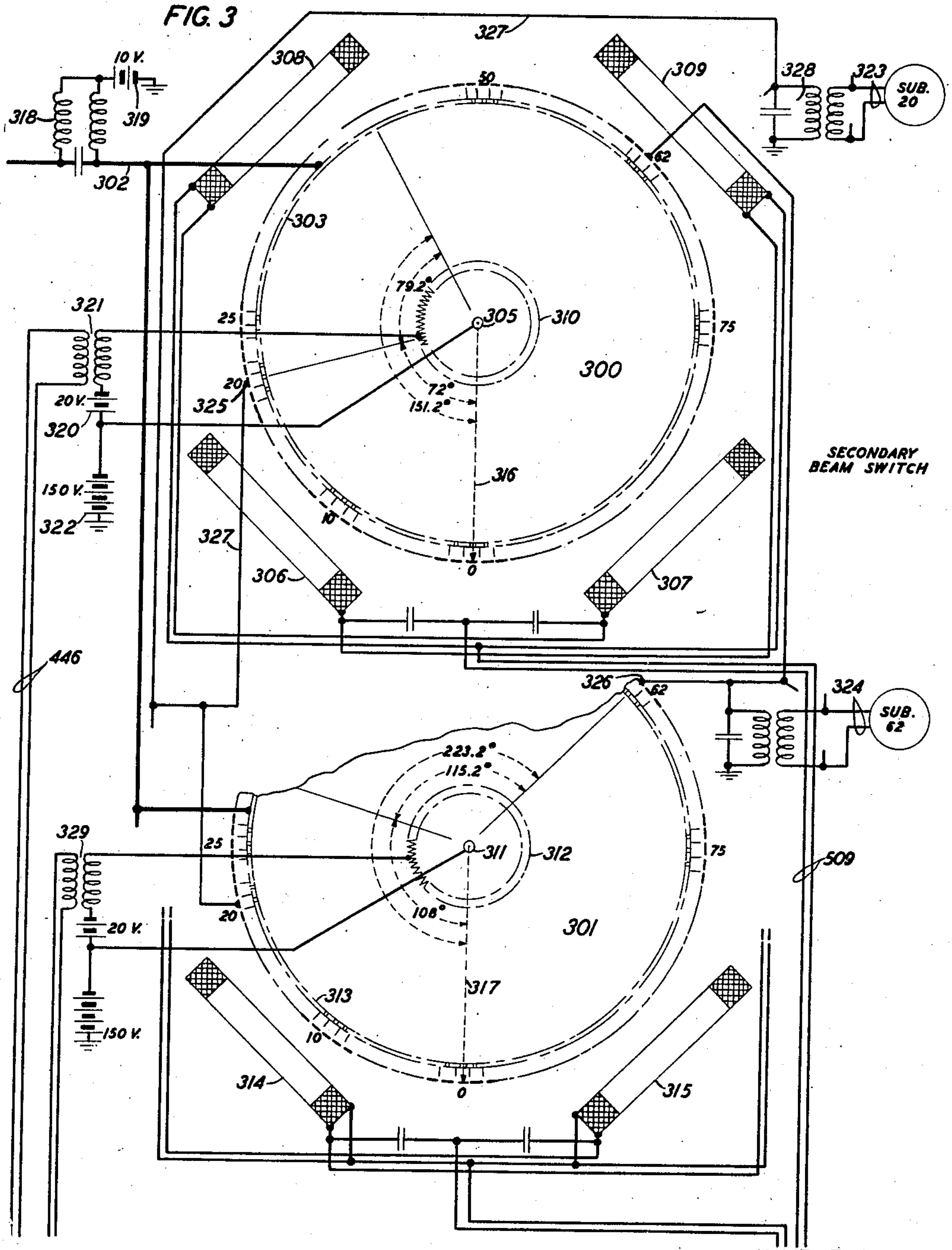

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FIG. 4

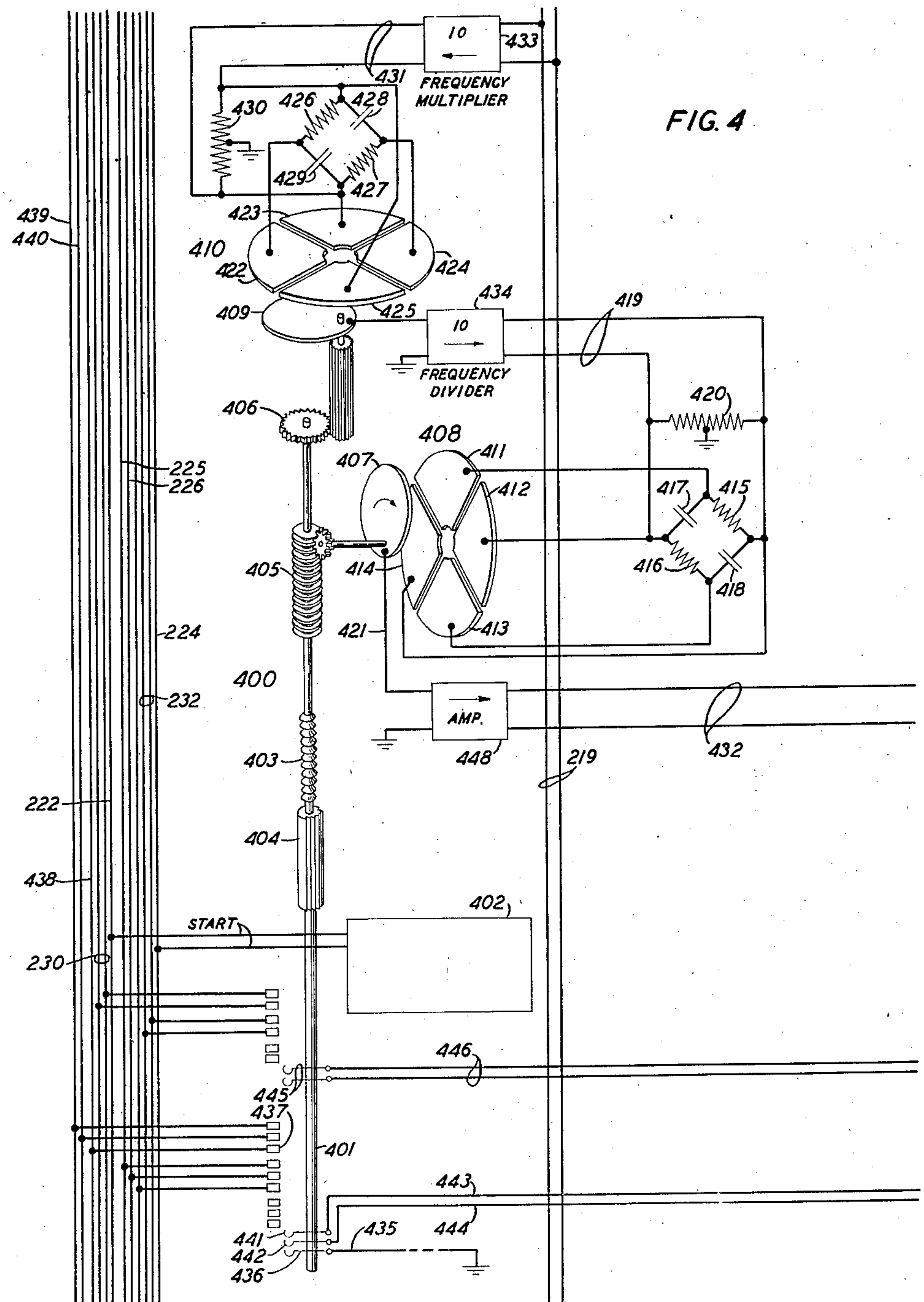

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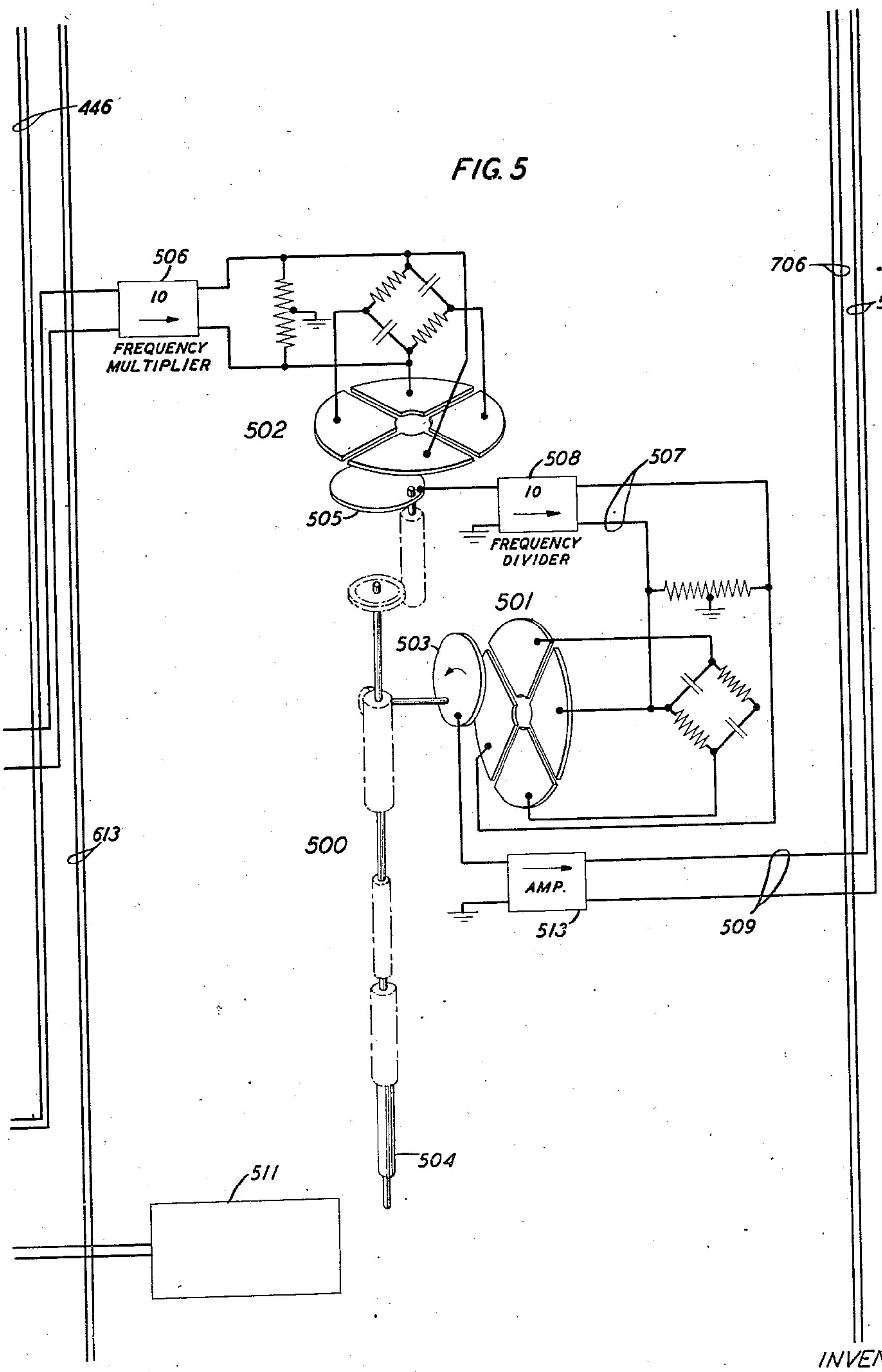
FIG. 5



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Filed Oct. 9, 1942 7 Sheets-Sheet 6

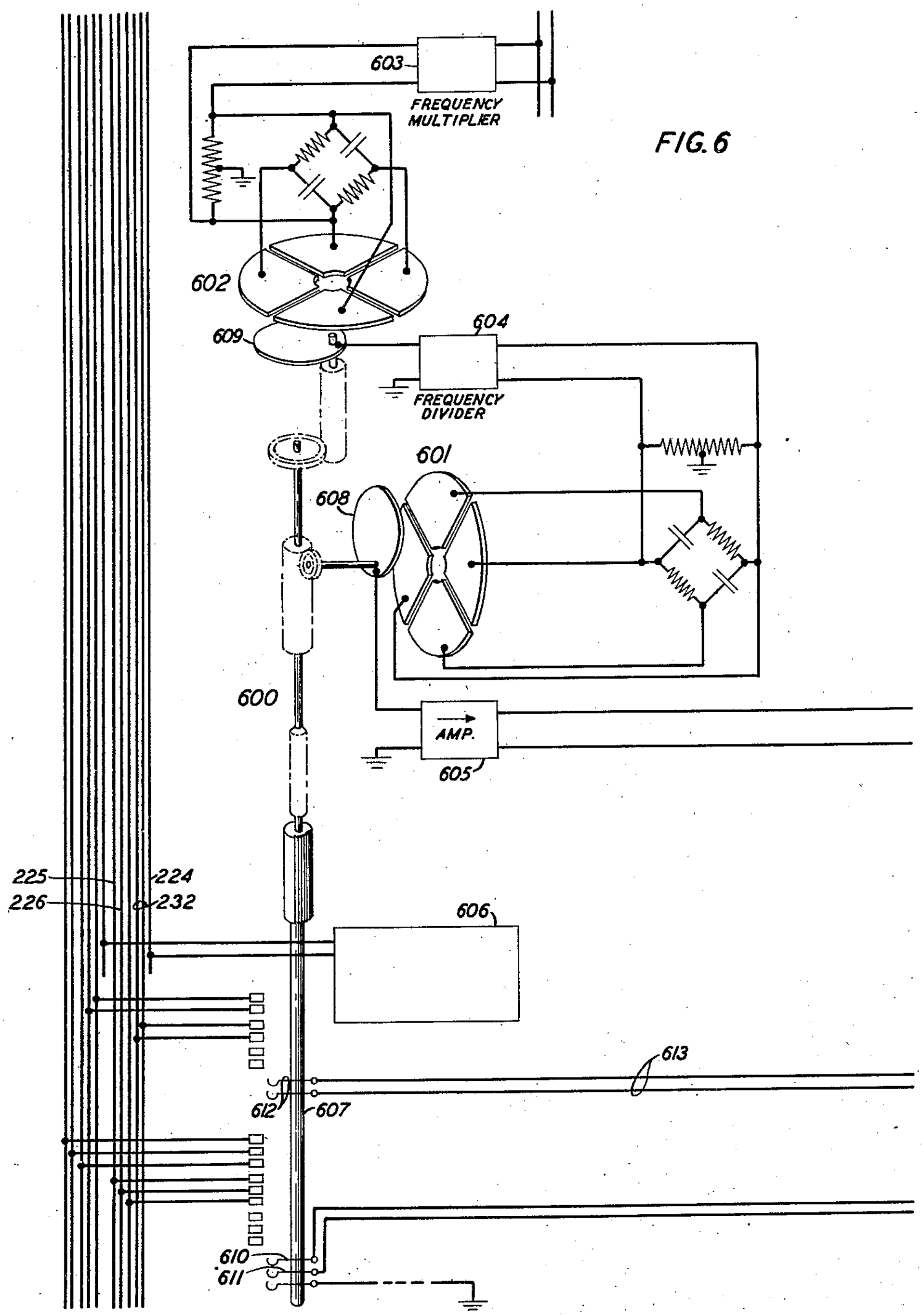

FIG. 6

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Filed Oct. 9, 1942 7 Sheets-Sheet 7

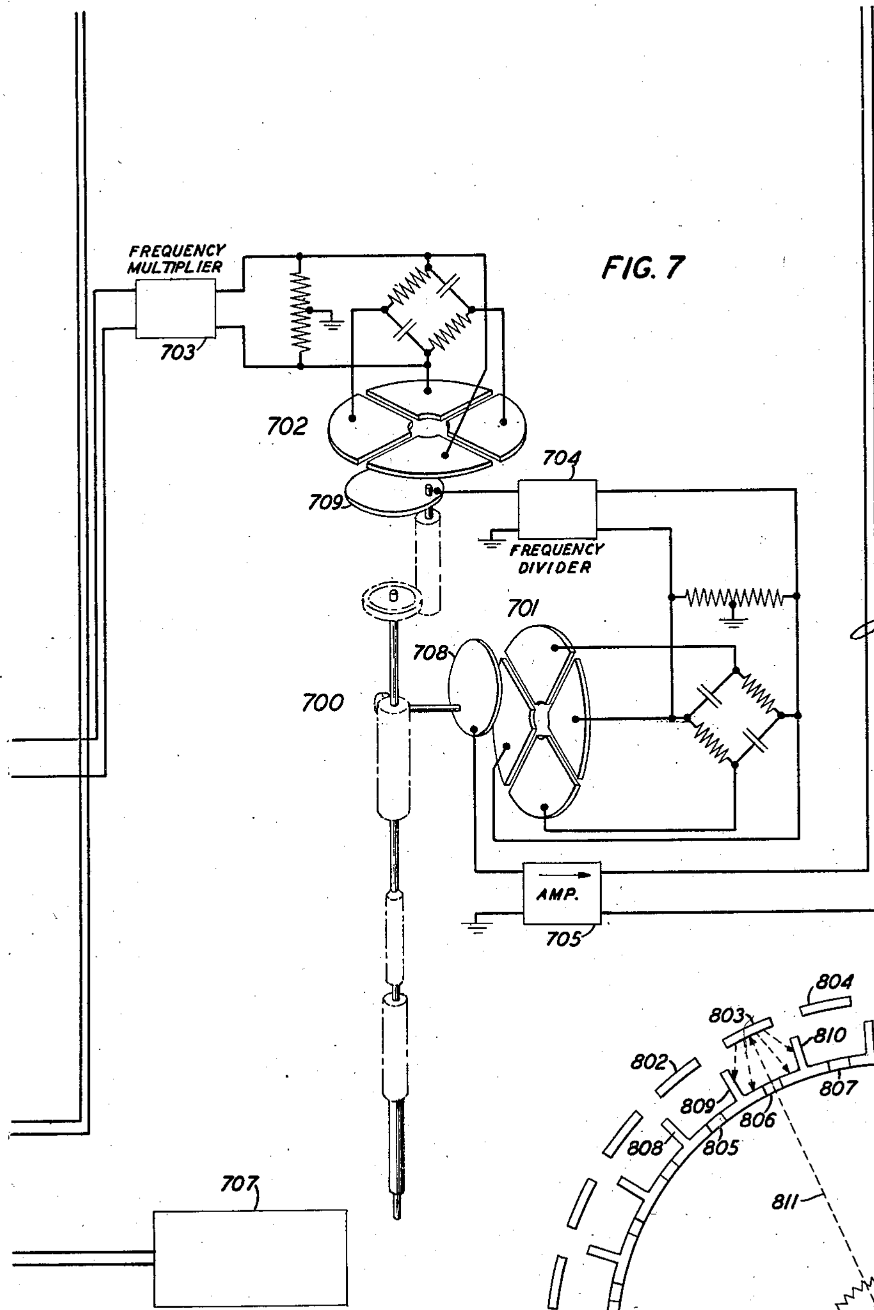

FIG. 7

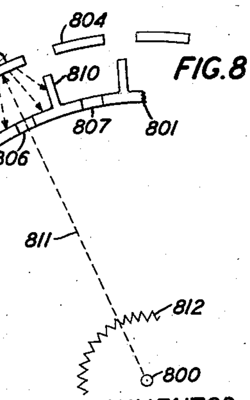

FIG. 8

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Patented June 26, 1945

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2,379,221

COMMUNICATION SYSTEM

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Application October 9, 1942, Serial No. 461,439

19 Claims. (Cl. 179—18)

This invention relates to electrical switching methods and switching devices and particularly to these methods and devices when applied to communication systems and to signaling systems in general.

The objects of the invention are to simplify the devices used to perform the switching of communication lines and other electrical circuits; to eliminate to a large extent the moving mechanisms heretofore used for this purpose; to reduce the number of switching stages necessary for the establishment of connections between telephone or other lines; to increase the speed with which connections may be established; and in other respects to obtain improvements in switching methods and devices.

Many varieties of automatic switching mechanisms have been proposed in the past for interconnecting the lines of telephone, telegraph, and other communication systems. In most all cases these prior mechanisms have depended largely upon the use of electromechanical devices in which moving parts serve to perform the selective and connecting operations involved in the establishment of the desired connections. While some of these types have been developed to a high degree of reliability, it is true nevertheless that the presence of moving mechanical elements imposes limitations on the speed of operation and also introduces other problems. Also there have been a number of suggestions heretofore for the use of the cathode beam tube for selecting telephone lines and other similar circuits. Furthermore, it has been previously suggested to use cathode beam tubes as distributors in systems of the usual multiplex distribution type.

In accordance with the present invention improvements and advantages are obtained over these prior devices by means of a switching system in which electrical connection may be established between any two lines in a group, such as the calling and called lines in a telephone office, through the medium of scanning devices. More specifically a group of lines, having an appearance in a scanning field as calling or incoming lines, are scanned repeatedly and at high speed by an electron beam, such as that produced by a cathode beam tube, and at the same time the said group of lines, having another appearance in a second scanning field as called or outgoing lines, are scanned repeatedly by a second electron beam. Normally these two beams are in synchronism and in phase such that each line in the incoming field is electrically connected to the corresponding line in the outgoing field through the medium of the beams once for each scanning cycle. The system is provided, however, with means for varying the relation of the two scanning beams in accordance with information received concerning the connection that is desired. When, therefore, it is desired to establish a connection between any calling line and any called line, the relation between the two beams is varied by an amount corresponding to the identity of these lines, so that each time the first beam engages the calling line the second beam simultaneously engages the called line. Thus the calling and called lines are connected together once per cycle, and the scanning rate is so rapid that a substantially continuous connection is maintained.

Another and related feature of the invention is a system in which the lines in the incoming scanning field and the lines in the outgoing scanning field constitute two separate groups of lines or trunks. For example, the outgoing lines may be a group of trunk circuits over which calls are extended from the incoming lines or trunks. By subdividing the outgoing lines into subgroups it is possible to choose any one of a number of different directions for routing the incoming calls.

Another feature of the invention is a scanning system in which the elements in the scanning fields are variably energized in accordance with the current variations in the lines produced by the speech or communication signals therein, and these variable energizations are communicated from one line to another by means of the intervening electron beams.

Another feature of the invention is a system in which the designations of the lines or other circuits to be connected for conversation through the scanning beams are utilized to introduce a phase displacement between said beams, so that said beams engage the calling and called lines simultaneously each time they pass through a scanning cycle.

Another feature of the invention is a system in which the scanning devices are driven synchronously from a common source of high frequency current and in which the designations of any pair of lines or circuits to be interconnected are used to produce a corresponding shift in the phase of the current supplied to drive one of said beam devices, thereby effecting a phase relation between the synchronously moving beams such that they engage simultaneously the desired pair of lines or circuits on each scanning cycle.

Another feature of the invention is a system in which the lines have an appearance in a primary beam scanning device and also have appearances in each of a plurality of associated secondary beam scanning devices, the beams of all devices being driven synchronously over the lines appearing therein, together with means for introducing definite and varying phase displacements between the beams of said secondary scanning devices and the beam of said primary device, so that simultaneous communications may take place between any desired number of pairs of lines.

These and other features of the invention will be discussed more fully in the following detailed specification.

In the drawings accompanying the specification:

Fig. 1 is a conventional diagram illustrating a telephone system incorporating the features of the present invention;

Figs. 2 to 7, inclusive, when arranged in the order illustrated in Fig. 9 disclose the system of Fig. 1 in greater detail;

Fig. 2 discloses a primary beam switch in which the subscribers' lines or other circuits appear and also shows two of these lines;

Fig. 3 shows two of the secondary beam switches in which the subscribers' lines also appear as well as other circuits with which it is desired to make connection;

Figs. 4 and 5 show a pair of designation registers for registering the numbers of calling and called lines respectively;

Figs. 6 and 7 disclose a second pair of designation registers; and

Fig. 8 is an enlarged fragmentary view illustrating the structure of the beam switches.

The invention in its broader aspects contemplates a multiplex system in which a plurality of communication channels are established concurrently for voice communication, telegraph signaling or transmission of any other desired kind. In the present disclosure, however, a telephone system has been chosen for the purpose of illustrating the invention. It is also assumed that there are one hundred lines in this system, all of which may be subscribers' lines if desired or a part of which may be trunks, such as those interconnecting one telephone office with another. In any event it will be obvious that the invention is not limited to any particular capacity nor to any particular division or disposition of the circuits comprising this system.

Referring first to Fig. 1, there is illustrated diagrammatically a single primary beam switch 100 in which the incoming lines of a group have individual appearances in a circular row of electrodes. Two of these lines, those having the designations "30" and "42" are shown in the drawing. The primary beam switch 100 is connected over a common transmission medium 101 to a plurality of secondary beam switches 102, 103, etc., the number of these secondary switches corresponding to the number of permissible simultaneous communications. The switches 102 and 103 are similar in structure to the switch 100, and the lines appearing in the switch 100 also have the same relative spatial appearance in each of the switches 102, 103, etc. Two subscribers' lines, No. 62 and No. 20, are shown outgoing from the secondary switches. If it is assumed that the system comprises one hundred subscribers' lines and that the switches have a capacity for one hundred circuits, then the entire circumferential row of electrodes in each of these switches is occupied by the subscribers' lines. In other words, lines numbered "0" to "99" would appear in spatial sequence around the circumference of switch 100 and would also be multipled to appear in the same spatial sequence around the circumference of each of the secondary switches 102, 103, etc. However, if it is desired to include trunks or other circuits incoming from and outgoing to distant points, a portion of the appearances around the circumference of the beam switches 100, 102, 103, would be devoted to these incoming and outgoing circuits, and the remainder of the appearances in these switches would be devoted to the subscribers' lines, which would also have the corresponding spatial appearances in the beam switches. One of the incoming circuits 104 and one of the outgoing circuits 119 are illustrated in the drawing.

A plurality of designation registers 105, 106, etc., are provided for registering the designations of any pair of lines or circuits between which it is decided to establish a communication connection by way of a pair of beam switches 100, 102. The register 105 comprises two stepping devices 107 and 108 which are essentially the same in structure as the well-known two-motion step-by-step switch used in automatic telephone systems. The subscribers' lines appear according to their numerical designations in the terminal banks of the stepping device 107, which operates automatically, like a line finder, to find the terminals of any line on which a calling condition is present. Having found the calling line, the vertical and rotary movements performed by the stepping device 107 are a measure or a registration of the tens and units digits of the line. As will be explained hereinafter, these vertical and rotary movements cause the setting of a pair of variable condensers which together comprise a phase shifter 109. The other step-by-step device 108 of the register 105 is similar to the finder 107, except that it responds to the impulses transmitted by the calling subscriber to perform vertical and rotary movements representing the tens and units digits of the called line or circuit and in so doing imparts corresponding settings to the condensers of the phase shifter 110.

The purpose of the phase shifters 109 and 110 is to impose a phase shift in the voltage taken from the beam-driving source 111 which is an exact measure of the spatial separation of the calling and called lines in the primary and secondary beam switches. Thus if the beams 112 and 113, which are driven in synchronism over their circumferential rows of electrodes by the common source 111, are in phase with each other, they encounter simultaneously the two appearances of each of the successive lines over which they move. But by setting the phase shifters 109 and 110 in accordance with the designations of the calling and called lines it is possible to shift the phase of the beam 113 with respect to the phase of beam 112 by an amount which corresponds to the spatial distance between the calling and called line appearances in the switches 100 and 102. Therefore, as the beams rotate in synchronism they encounter the calling and called lines simultaneously once per revolution.

In like manner the register 106 comprises a step-by-step line finder device 114 having an associated phase shifter 115 and a stepping device 116 having an associated phase shifter 117. It will be noted that the registers 105 and 106 are common to all of the subscribers' lines and are associated respectively with the secondary beam switches 102 and 103. And in like manner for each of the remaining secondary beam switches not disclosed in the drawing a corresponding register is provided.

Referring now to Figs. 2 to 7, the subscribers' lines, which are assumed to be numbered from "0" to "99," appear in the central office in individual control and transmission circuits. For example, lines **200** and **201** appear in the usual controlling circuits **202** and **203** respectively and also through suitable condensers and transformers in the transmission circuits **204** and **205** respectively. These lines also appear in the primary beam switch **206**. To this end the switch **206** comprises a circumferential row of one hundred anodes, and each one of these anodes is connected by a conductor to the transmission circuit of one of the subscribers' lines. For example, subscriber's line **200**, the designation of which is "42," is connected by way of conductor **207** to the forty-second anode **208**, and line **201**, the number of which is "30," is connected by way of conductor **209** to the thirtieth anode **210** in the beam switch **206**. The beam switch **206** includes a central electron-emitting cathode **211**, a collector grid **212** and a set of driving coils **213**, **214**, **215** and **216**. The central cathode, the collector grid and the circumferential anodes are all enclosed in a sealed vacuum tube. The driving coils are arranged on the exterior of the tube in any convenient manner and serve to set up a rotating magnetic field which causes the electron beam **217** (virtual or real) to rotate at a velocity depending on the frequency of the energizing source **218**. For a more complete description of the general principles of the rotating radial beam tube reference is made to the patent to A. M. Skellett 2,217,774 of October 15, 1940.

The primary beam switch **206** is paired with each of a plurality of secondary beam switches **300**, **301**, etc., over a common transmission conductor **302** which interconnects the collector grid **212** of the switch **206** and the collector grids **303**, **304**, etc., of the secondary beam switches. The beam switch **300** is substantially the same as switch **206**; it has a circular row of one hundred anodes spaced and numbered in the same order, a collector grid **303**, a central electron-emitting cathode **305** and the collector driving coils **306**, **307**, **308** and **309**. In addition the switch **300** is provided with a control grid **310**, the purpose of which will be explained hereinafter. Likewise the secondary beam switch **301** comprises a central cathode **311**, a control grid **312**, a collector grid **313**, a circular row of one hundred anodes and driving coils, two of which, **314** and **315**, are illustrated in the drawings.

When the primary beam switch **206** is paired with the secondary beam switch **300** for establishing communication between a pair of subscribers' lines, the relative position or phase of the beams **217** and **316** is controlled by the pair of phase-shifting registers **400** and **500**. As above mentioned, the register **400** is essentially a two-movement, step-by-step finder switch. It has a brush-carrying shaft **401** which is stepped vertically to select any one of ten levels of terminals, and which is stepped in a rotary direction to select any individual set of terminals in the level. The starting, controlling and stepping mechanism **402** is illustrated conventionally and may be of the usual well-known character. In addition to the standard vertical and rotary ratchets **403** and **404** by which the brush shaft **401** is driven vertically and in its rotary directions, the shaft **401** carries a driving ratchet **405** and a driving pinion **406**. The driving ratchet **405** serves to adjust the movable plate **407** of the variable condenser **408** by an amount corresponding to the vertical movement of the shaft **401**; and the pinion **406** serves to set the movable plate **409** of the variable condenser **410** by an amount corresponding to the rotary movement of said shaft. The shaft **401** takes a number of vertical steps varying from one to ten in accordance with the tens digit of the calling subscriber's line and in so doing sets the movable condenser plate **407** in any one of ten positions with respect to the stationary plates **411**, **412**, **413** and **414**. The gearing between the plate **407** and the ratchet **405** is such that the plate **407** makes a complete revolution of 360 degrees for ten steps of the shaft **401**. Therefore, each of the successive values of the tens digits is represented by an angular rotation of the plate **407** which is a multiple of 36 degrees.

The four stationary plates of the condenser **408** are connected to the corners of an electrical bridge comprising resistors **415** and **416** and the condensers **417** and **418**, and the bridge input circuit **419** is also bridged by a resistor **420** having its mid-point connected to ground. When an alternating voltage is applied to the input circuit **419**, the bridge applies potentials to the four quadrant plates **411**, **412**, **413** and **414** to establish adjacent these plates an electrostatic field the intensity of which varies in synchronism with the alternating voltage in the circuit **419**. But the phase of this electrostatic field, relative to the phase of the voltage in the circuit **419**, varies by four equal steps around the cycle, 90 degrees for each of the stationary condenser plates. The potential on the movable plate **407**, therefore, varies in phase by increments of 36 degrees each for the ten different rotary positions assumed by said movable plate. For a more detailed description of the general principles of phase-shifting devices of this character reference is made to the patent to L. A. Meacham, 2,004,613 of June 11, 1935.

In like manner the phase shifter **410** has ten different positions representing the ten different values of the units digit of the calling line, and each of these positions of the movable plate **409** is a corresponding multiple of 36 degrees. The stationary plates **422**, **423**, **424** and **425** are connected to the bridge comprising resistors **426** and **427** and condensers **428** and **429** which, together with the grounded resistor **430**, is connected across the input circuit **431**. The effect of the variable condenser **410** and the associated bridge circuits is, like condenser **408**, to shift the phase of the voltage in the input circuit **431** by ten equal steps of 36 degrees each through the entire cycle of 360 degrees.

If, therefore, the voltage from the beam-driving source **218** is applied through the phase shifters **410** and **408** in series, the voltage in the output circuit **432** will have a phase relative to that of the source **218** which has been shifted by a multiple of 36 degrees which is equal to the numerical sum of the tens and units digits. In other words, the units phase shifter would, under this assumption, produce a shift of the same magnitude as that produced by the tens digit. It is necessary, therefore, to reduce the shift effected by the units digit to one-tenth of the shift effected by the same tens digit. The necessity for doing this can best be understood by referring for the moment to the beam connectors. Since there are 100 lines appearing in ten groups of ten around the 360 degrees of the beam switch, each group of ten occupies an angular distance of 36 degrees. The phase shift, therefore, of the beam 316 over a group of ten lines corresponds to one step of the tens digit phase shifter 408, namely, a 36-degree shift. However, a shift of the beam 316 from one line to the next within a group of ten corresponds to one-tenth of the shift produced by a single step of the units phase shifter 410. Hence in order that the phase shifter 410 may produce increments of phase shift of 3.6 degrees each rather than increments of 36 degrees, a frequency multiplier 433 is inserted between the source 218 and the input circuit 431 of the phase shifter 410. The multiplier 433 multiplies the frequency of the source 218 ten times. Although the shifter 410 shifts the frequency of the input voltage by steps of 36 degrees, each one of these steps in reality corresponds to only a 3.6-degree shift when compared with the original frequency. In the output circuit of the phase shifter 410 a frequency divider 434 is inserted for the purpose of dividing the frequency of the output voltage by ten and thus restoring it to the same frequency as the source 218. Thus, the voltage taken from the source 218 is applied to the units shifter 410 and appears in the output circuit 419 displaced in phase by a multiple of 3.6 degrees which is equal to the numerical value of the units digit of the line which causes the setting of the phase shifter 410. This voltage with the units phase shift therein is then applied to the tens phase shifter 408 as above explained and appears in the output circuit 432 with an added shift which is equal to the multiple of 36 degrees corresponding to the numerical value of the tens digit that causes the setting of the phase shifter 408. We have, therefore, in the output circuit 432 a voltage which is displaced in phase, relative to the phase of voltage 218, which is an exact measure of the designation of the calling subscriber's line. An amplifier 448 is provided if desired for increasing the energy in the output circuit 432.

The phase displacement of the beam 316, however, must taken into account not only the number of the calling line but also the number of the called line. To this end the phase shifting register 500, which responds to the number of the called line dialed by the calling subscriber, is provided with a tens digit phase shifter 501 and a units digit phase shifter 502. These phase shifters are identical with those shown in Fig. 4; the shifter 501 comprises a movable plate 503 driven through ten successive steps by the vertical movement of the shaft 504, together with the stationary plates and associated bridge circuits; and the shifter 502 comprises the movable plate 505 which is rotated through ten equal steps by the rotary movement of the shaft 504, together with the four stationary plates and the associated bridge circuits.

Since the resultant phase shift for the beam of the secondary switch relative to the phase of the beam of the primary switch is the algebraic sum of the phase shifts representing the calling and called lines, the calling line phase shifters of Fig. 4 are connected in series with the called line phase shifters of Fig. 5 before the final voltage is applied to the beam-driving coils of the secondary switches. To this end the output circuit 432 from the phase shifter 408 is connected to the input circuit of the phase shifter 502. As in the case of the phase shifter 410, a frequency multiplier 506 is introduced to multiply the frequency of the voltage in the circuit 432 by ten before applying it to the units phase shifter 502. The effects of this multiplication is, as explained, to produce a voltage in the output circuit 507 which is shifted by units of 3.6 degrees each with respect to the phase of the voltage in the circuit 432. The voltage in the output circuit 507 is restored to the normal frequency of the source 218 by the frequency divider 508. This voltage is then applied to the tens phase shifter 501 and the resultant voltage in the output circuit 509 has a phase equal to the algebraic sum of the phases representing the calling and called lines. A suitable amplifier 513 serves to increase the voltage in the output circuit 509.

Since it is the difference between the spatial locations of the calling and called lines in the beam switches that determines the phase difference necessary to bring the beams onto these lines simultaneously as they sweep through their cycles, the phase shifters of the calling and called lines are arranged to produce shifts of the opposite sense. More specifically, the phase shifters 408 and 410 produce a shift of the negative sign in the voltage wave, whereas the phase shifters 501 and 502 of the called line produce a phase shift of the positive sign. This difference of sense may be obtained by arranging the driving connections of the plates 407 and 503 such that they rotate in opposite directions with respect to the stationary condenser plates and by arranging the shafts 401 and 504 to rotate the movable plates 409 and 505 in opposite directions. If the number of the calling line is numerically greater than the number of the called line, the negative phase shift of the secondary beam caused by the phase-shifting register 400 exceeds the positive phase shift of the beam caused by the phase-shifting register 500 by the difference between the two numbers, and the negative sign before the resultant phase shift applied to the secondary beam indicates that this beam lags the primary switch beam by the phase angle which equals the spatial separation between the calling and called lines. However, if the number of the called line is greater than that of the calling line, the positive phase shift produced by the register 500 exceeds the negative phase shift produced by the register 400, and the positive sign before the resultant phase shift applied to the secondary beam indicates that the secondary beam leads the primary beam by the angular amount representing the spatial separation of the lines. And it will be found that in all cases the algebraic sum of the negative phase shift produced in accordance with the number of a calling line and the positive phase shift produced in accordance with the number of a called line gives a resultant phase shift between the primary and secondary beams which is an exact angular measure of the spatial separation of the lines.

It will be noted that one of the advantages of multiplying the frequency by ten before and dividing it by ten after applying the voltage to the units phase shifters is the uniformity obtained in the degree of motion and accuracy required for both the tens and units shifters. If desirable, however, it would be possible to obtain the necessary shift intervals of 3.6 degrees for the units digits without changing the frequency by arranging the movable plates of the units shifters to move through distances which are one tenth of the distances traversed by the tens shifters for the same digital values. Also it will be understood that where the frequency multipliers and dividers are used they are arranged to preserve the proper relation between phases of the voltage before and after the multiplication and division. It is not considered necessary to show these multipliers and dividers in detail since devices of this character are well known in the art. As mentioned, however, it is recognized that care must be taken to prevent the existence of random phase variations particularly in the frequency dividers where this tendency is somewhat more pronounced. If desirable this requirement may be met by the use of frequency dividers of the types disclosed in the article entitled Frequency Division without Free Oscillation, by D. G. Tucker and H. J. Marchant, Post Office Electrical Engineers' Journal, July 1942, volume 35, Part 2, page 62. However, it will be understood the frequency controlling devices used herein may be of any suitable and desirable type.

When the primary beam switch 206 is paired with the secondary beam switch 301 for establishing communication between a pair of subscribers' lines, the relative position or phase of the beams 217 and 317 is controlled by the pair of phase-shifting registers 600 and 700. The calling line register 600, like the register 400, is a line-finding mechanism having access to all of the subscribers' lines and includes a tens phase shifter 601 and a units phase shifter 602. Likewise, the called line register 700 corresponds to register 500 and comprises a tens phase shifter 701 and a units phase shifter 702. Voltage from the alternating source 218 is applied to shifter 602 through a multiplier 603 which multiplies the frequency by ten and the output voltage from the shifter 602, after having its frequency divided by ten by the divider 604, is applied to the phase shifter 601. The output voltage from the shifter 601 is amplified by amplifier 605, following which its frequency is again multiplied by ten by the multiplier 703 and applied to the shifter 702. The output voltage from the shifter 702 is restored to its original frequency by the frequency divider 704 and is then applied to the phase shifter 701. The voltage output from the shifter 701 is amplified by amplifier 705 and is then applied over circuit 706 to the quadrature coils 314, 313, etc. of the secondary beam tube 301.

In like manner other pairs of phase-shifting registers and secondary beam switches (not shown) are provided, the total number being selected in accordance with the maximum number of conversations to be permitted.

From the foregoing it will be seen that any pair of lines may be connected for communication through the primary and secondary switch beams by utilizing a single source of alternating voltage 218 to drive the primary beam in phase with the voltage from said source and to drive the secondary beam with the necessary phase displacement introduced. Accordingly, the source 218 is connected directly to the quadrature coils 213, 214, 215 and 216 of the primary switch 206 and is connected by way of circuit 219 and the several pairs of phase-shifting registers in parallel to the quadrature coils of the corresponding secondary beam switches. For example, the circuit 219 is connected through the phase shifters 410, 408, 502 and 501 in series, thence over circuit 509 to the quadrature coils of the beam switch 300. Also the circuit 219 is connected through the phase shifters 602, 601, 702 and 701 and thence over circuit 706 to the quadrature coils of the beam switch 301. And in like manner the supply circuit 219 is connected through the phase shifters of succeeding pairs of phase-shifting registers to the quadrature coils of the corresponding secondary beam switches. The beam 217 of the primary switch 206 is driven in synchronism and in phase with the voltage of source 218, which may be of any suitable frequency, such as 10,000 cycles per second. The beam 316, however, when paired with the beam 217 for a particular conversation, is driven in synchronism with the voltage of the source 218 and with the beam 217 but with a phase displacement which measures the difference between the calling and called line numbers. And the same is true of the beam 317 and of the beams of other secondary switches not shown in the drawings.

It is, of course, desirable in a communication system, such as the one here illustrated, that the parties be able to carry on a two-way conversation. This facility is made possible in the present system, notwithstanding the unilateral character of the usual cathode-beam tube, by taking advantage of the well-known phenomenon of secondary electron emission. The space between the collector grid and the ring of anodes of the rotary beam tube disclosed herein is capable of conducting signals in both directions if the proper relative voltages are selected. The central cathodes are connected to the negative pole of the battery which produces the electron beam, the positive pole of this battery being grounded, the anodes are connected respectively through their individual transmission circuits to ground, and the common collector grid is connected to the positive pole of a battery of relatively low voltage, which also has its negative pole grounded. For example, the rotary beam switch 206 has its central cathode 211 connected to the negative pole of battery 220, and the positive pole of this battery is connected directly to ground. The individual anodes 208, 210, etc., are connected through their transmission circuits 204, 205, etc., to ground. And the collector grid 212 is connected over the common transmission conductor 302 through impedance coil 318 to the positive pole of battery 319. The battery 220 sets up a voltage, say 150 volts, between the cathode 211 and each anode, which is sufficient to cause a beam of electrons to flow from the cathode to the anode through slits or openings in the collector grid 212 notwithstanding the positive potential impressed upon the collector grid by the relatively small battery 319, say 10 volts. If, while the electron beam 217 is passing through the collector grid 212 to an individual anode, the potential of the anode is varied in accordance with the speech signals originated in the line connected to said anode, the intensity of the secondary emission set up by the impingement of the beam on the anode varies correspondingly and in turn imparts a corresponding variation to the potential of the collector grid, to which the electrons of secondary emission are directed. The variations of grid 212 are impressed over the common medium 302 to the collector grid of the associated secondary switch, say the grid 303 of switch 300. These potential variations on the grid 303 in turn cause similar variations in the intensity of the electron beam 316 as it passes from the cathode 305 through the collector grid to impinge upon a particular anode, and these variations in the beam are reflected by corresponding potential variations on the anode, which in turn are impressed as speech signals upon the called line connected to said anode. On the other hand, if speech signals are originated in the called line which is connected to a particular anode in the beam switch 300, the potential variations of the anode cause corresponding variations in the secondary emission resulting from the impingement of beam 316 on said anode, and the variations in secondary emission cause in turn corresponding variations in the potential of the collector grid 303 to which the secondary emission is directed. The potential variations of the grid 303 are transmitted over the medium 302 to the collector grid 212, and the grid 212 varies the intensity of the beam 217 as it passes from the cathode 211 through the grid to the particular anode with which the calling line is associated. Accordingly the potential of the anode is varied in accordance with speech signals and results in the transmission of these signals over the calling subscriber's line. Thus the calling and called subscribers may talk to each other in either direction over the established connection, making use of the primary and secondary emissions of the beam switches.

A clearer understanding may be had of the physical structure of the beam switches by reference to Fig. 8. This figure shows the central cathode 800, the collector grid 801 and the annular series of anodes 802, 803, 804, etc. As shown in the Skellett Patent 2,217,774 referred to herein, the cathode 800 may comprise a filamentary element located along the central axis of the cylindrical envelope of the tube, and the anodes may comprise a series of vertically disposed cylindrical strips arranged concentrically with respect to the cathode. The collector grid 801 consists of a cylinder having a series of vertical slots 805, 806, 807, located in line with the central cathode and the respective anodes. The collector grid 801 is also provided with integral fins 808, 809, 810 which act as partitions to form spaces individual to the respective anodes. The purpose of these spaces between adjacent fins is to confine the secondary electron emission from the associated anodes to prevent interference between circuits connected to adjacent anodes. In the figure the primary emission from the central cathode 800 is illustrated by the electron beam 811, which in the construction described is in fact in the form of a sheet of electrons emerging from the filamentary cathode 800. This beam of electrons passes through the slots in the collector grid, one after the other, as the beam rotates, and, as illustrated, after passing through the slot 806 impinges upon the associated anode 803. The impingement of the beam on the anode 803 causes the secondary emission of electrons which are attracted back to the collector grid 801 by reason of the potential difference between the anode and the collector grid. As above noted and as illustrated in the figure, this secondary emission is confined to the space formed by the fins 809 and 810 and the anode 803. The beam switch shown in Fig. 8 is also provided with a control grid 812 the purpose of which will be explained presently.

Inasmuch as the primary beam switch 206 may be paired with a plurality of secondary beam switches for concurrent conversations between a number of pairs of lines, it is desirable that the rotating beam of each of the secondary switches shall remain virtual in all of its angular positions around the cycle, except the position corresponding to the called line. In this position the virtual beam is transformed into a real beam in order that conversation may take place between the lines of the conversational pair. To effect this transformation of the secondary switch beams these switches are provided with control grids 310, 312, etc. The control grid 310, for example, is biased negatively with respect to the cathode 305 by means of a biasing battery 320 which is connected to the grid through the coil of high frequency transformer 321. The normal bias on the grid 310 is sufficient to prevent the flow of electrons from the cathode 305 to the anodes in response to the voltage of battery 322. Therefore, as t e magnetic field rotates about the switch 300, a virtual beam rotates therewith until the position is reached occupied by the anode to which the called line is connected. At this same instant the rotating meam 217 of the primary switch, which exists always as a real beam, is connected to the anode to which the calling line is connected. As the beam 217 rotates through its successive cycles it generates in the transmission circuits 204, 205, etc., connected to the respective anodes, momentary impulses of high frequency, namely, a frequency which is one hundred times the frequency of the source 218. When, therefore, the beam 217 engages the anode of one of the lines of a pair engaged in conversation the high frequency impulse developed in the associated transmission circuit (204, for example) is passed by the high frequency transformer 221 and is transmitted through the associated register 600 through the high frequency transformer 321 to the control grid 310. The polarity of this high frequency impulse is such that it overcomes momentarily the negative bias on the control grid 310 whereupon the beam 316 assumes a real character and electrons flow from the cathode 305 to the anode of the other line of said pair. An instant later, as the primary beam 217 moves off the anode of the first-mentioned line and passes to the next successive anode, the high frequency impulse ceases, the negative bias of the grid 310 is restored, and the beam 316 resumes its virtual character until it has completed another cycle.

A detailed description will now be given of the operation of the system, assuming that a plurality of conversations are taking place concurrently. For this purpose it will be assumed that the subscriber of line 200 (line No. 42) wishes to converse with the subscriber of line 323 (line No. 20) and that the subscriber of line 201 (line No. 30) wishes to converse with the subscriber of line 324 (line No. 62). When the line 200 calls, a starting condition is applied to conductor 222, and, if the registers 400, 500 are the set next allotted for use, the controlling mechanism 402 of the finder register 400 starts the register in operation to hunt for and seize the calling line 200. The number of the calling line being "42," the brush shaft 401 takes four vertical steps and two rotary steps to bring the brush sets into engagement with the terminals representing the calling line. Accordingly, the movable condenser plate 407 is rotated to its fourth position relative to the stationary plates, and the movable plate 409 is rotated to its second position relative to the stationary plates. When the register 400 reaches the terminals of the calling line, a test circuit is closed over conductor 435, brush 436, terminal 437 to conductor 438 on which a hunting condition exists. Closure of this circuit causes the cessation of the hunting operation, and ground is thereupon applied over conductor 435 to render the line 200 busy to other registers. The loop of the subscriber's line 200 is now extended over conductors 439 and 440 through brushes 441 and 442, conductors 443 and 444 to the operating mechanism 511 of the associated called line register 500. The calling subscriber manipulates his dial 223 to transmit the tens and units digits "2" and "0" of the called line 323. These impulses operate the register 500, which takes two vertical steps and ten rotary steps to position the movable plates 503 and 505 correspondingly. The shift of phase, which is negative in sense, imposed by the register 400 upon the voltage in the circuit 432 is equal to 4×36 degrees +2×3.6 degrees or −151.2 degrees; and the shift, which is positive in sense, imposed by the register 500 upon the voltage in circuit 509 is equal to 2×36 degrees or +72 degrees. Therefore, the resultant shift of phase of the voltage appearing in the circuit 509 is −151.2 degrees +72 degrees or −79.2 degrees. Thus, as the beams 217 and 316 rotate in synchronism, each time the beam 217 reaches the anode 208, which occupies a radial position 151.2 degrees from the zero position the beam 316 engages the anode 325 which occupies a radial position 72 degrees from the zero position. In other words, the beam 316 is lagging the beam 217 by the fixed angle 79.2 degrees, which is the phase displacement introduced by the phase-shifting registers 400 and 500 in accordance with the numbers of the calling and called lines.

When the calling condition appears on the other calling line 201, the start circuit is closed and the next available set of registers 600 and 700 is taken for use. The operating mechanism 606 of the finder register responds to the starting condition and operates the shaft 607 three steps in a vertical direction and ten steps in the rotary direction to drive the movable plate 608 to its third position relative to the stationary plates and the movable plate 609 to its tenth position (a full cycle) relative to the stationary condenser plates. The setting of the register 600 on the terminals of the calling line 201 extends the calling line loop over the conductors 225 and 226 and brushes 610 and 611 to the operating mechanism 707 of the called line register 700. The calling subscriber manipulates his dial 227 to transmit the tens and units digits "6" and "2" of the called line 324, and the register 700 positions the movable plates 708 and 709 correspondingly. The negative phase shift introduced by the setting of the register 600 is equal to 3×36 degrees or −108 degrees, and the positive phase shift introduced by the register 700 is equal to 6×36 degrees +2×3.6 degrees or +223.2 degrees. Thus the resultant phase shift appearing in the circuit 706 is −108 degrees +223.2 degrees or 115.2 degrees. Thus, as the beams 217 and 317 rotate in synchronism, each time the beam 217 reaches the anode 210, which occupies a radial position 108 degrees from the zero position, the beam 317 engages the anode 326, which occupies a radial position 223.2 degrees from the zero position. In other words, the beam 317 is leading the beam 217 by 115.2 degrees which is the phase displacement introduced by the phase-shifting registers 600 and 700 in accordance with the numbers of the calling and called lines.

The transmission circuits for conversation between the subscribers of the two pairs of lines will now be described. As above explained, the real beam 217 of the primary switch is rotating in phase with and in synchronism with the voltage of the source 218, the virtual beam 316 of the switch 300 is rotating in synchronism with but 79.2 degrees behind the beam 217, and the virtual beam of switch 301 is rotating in synchronism with but 115.2 degrees ahead of beam 217. This relation continues as long as the subscribers remain in conversation. Assume that at a given instant the primary beam 217 has reached the angular position corresponding to the calling line 200 and is dwelling briefly on the anode 208. At this same instant the secondary beam 316 is dwelling on the anode 325 individual to the called line "20." If at this instant the calling subscriber is speaking, the voice currents in the line 200 are induced in the audio-frequency transformer 228, causing corresponding currents to flow in the transmission circuit 204 which includes the high frequency choke coil 229 and the primary winding of the high frequency transformer 221. At the instant we have chosen the voice currents flowing in the transmission circuit 204 impart over conductor 207 to anode 208 a certain potential corresponding to the intensity of the voice wave at that instant. This certain potential on the anode 208 imparts, through secondary electron emission, a certain corresponding instantaneous potential on the collector grid 212 and in the common transmission medium 302. Also at this same instant the beam 217, upon striking the anode 208, has produced an impulse of high frequency which is transmitted over conductor 207 through the transmission circuit 204 and the high frequency transformer 221 thence over conductors 230, brushes 445, conductors 446 to the primary winding of high frequency transformer 321. This impulse is induced in the secondary winding of the transformer 321, and as above explained, opposes the normal bias on the control grid 310, causing the beam 316 to strike or to change from its virtual to its real character. Since at the instant assumed the common medium 302 has assumed a certain potential, in accordance with the instantaneous value of the calling subscriber's speech, the collector grid 303 likewise takes up a corresponding potential. Therefore, the real beam 316 is controlled in its intensity in a manner to produce a proportional potential on the anode 325 on which it impinges. The anode 325 being connected by way of conductor 327 to the transmission circuit 328 of the called line "20," the successive potential values thus assumed by it in accordance with the rotation of the beam reproduce the audio-frequency wave and cause talking current to flow in the subscriber's line 323 representing the speech of the calling subscriber.

Conversely, if the called subscriber is speaking at the instant the beams 217 and 316 are engaging the anodes representing the calling and called lines 200 and 323 respectively, the current variations in the line 323 cause potential variations to be applied by way of conductor 327 to the anode 325 on which the real beam 316 is now impinging. The variations of potential on the anode 325 cause through the secondary electron emission corresponding variations on the collector grid 303 at the successive instances marked by the striking of the beam, and this succession of differing potentials are applied over the common medium 302 to the collector grid 212 of the beam switch 206. The appropriate succession of potentials of the collector grid 212 vary at the corresponding instances the intensity of the beam 217, resulting in a succession of differing potentials on the anode 208 which reconstruct the audio-frequency wave shape. The resulting voice variations are imparted over conductor 207 to the transmission circuit 204 and are induced through the transformer 228, causing the flow of talking current in the calling subscriber's line 200. For each of the rapidly recurring cycles of the beams 217 and 316, a fragment of the speech is transferred in this manner between the calling and called lines

260 and 326, the fragments following so rapidly upon each other as to give the impression of continuity to the speakers in accordance with the principles of the time division form of multiplex telephone system.

In a similar manner the synchronous beams 217 and 317 engage the anodes 210 and 326 simultaneously and repeatedly; at each such engagement a high frequency impulse is transmitted by way of transmission circuit 205, high frequency transformer 231, circuit 232, brushes 612, circuit 613, transformer 329 to the control grid 312, causing the beam 317 to strike; and transmission takes place in either direction between the calling line 201 and the called line 324.

When the subscribers have finished their conversation they replace their receivers on the switchhooks, and the calling condition is removed from the line circuits 202 and 203, permitting the release in any well-known manner of the register sets 400, 500 and 600, 700. These registers may now be selected in response to new calls on any of the subscribers' lines.

Thus it will be appreciated that the speech of each individual conversation is transmitted through this system, over the common connecting medium of it, as a rapid succession of sharp impulses, the successive peak values of any one set of which trace out the voice-frequency wave of that particular connection. It is this feature which enables the single rotating beam switch 100 (Fig. 1) to accommodate simultaneously calls over all of the lines associated with it. This it does by transmitting for each such line over the common medium for but a brief interval in accordance with the superposition principle of the time-division multiplex type of system. In that type of system two such rotating switches are employed, one at each end, which are operated in synchronism and in fixed phase relation, whereby a given line at one end is always connected with a given line at the other, and generally in the same relative position. The departure from this prior art in the present system, in respect to this time-division multiplex phase of it, is that the present system provides for connecting any one line at one end of the system with any other line at the other end.

It has already been explained that the invention contemplates the use of virtual as well as real beams of electrons. The controlling field which rotates the radial beam may be electrostatic instead of electromagnetic as illustrated. The invention also contemplates the use of beams of other forms of energy, and it should be understood that whenever the specification or claims speak of these beams either in motion or in their instantaneous positions these descriptions are intended to apply to the beams in their virtual nature as well as in their real form.

It will be understood that other types of phase shifters may be used if desired. For example the rotating condenser plate may be replaced by a succession of fixed networks comprising tapped condenser units which are connected to sets of contacts selected by the settings of the register switches.

What is claimed is:

1. The combination in a communication system of a group of lines, means for causing a beam of energy to scan said group of lines repeatedly and to establish communicative engagement with any desired line in said group, means for causing a second beam of energy to scan said group and to establish communicative engagement with any desired line in said group, and means for controlling the relation between said beams to establish communicative engagement simultaneously between any desired pair of lines in said group.

2. The combination of a communication system of a group of elements, means for producing two separate beams of energy, means for driving said beams synchronously to traverse the elements of said group repeatedly, circuit means including said beams in serial relation for establishing communication channels between elements of said group, and means for varying the phase relation between said beams for causing them to traverse any desired pair of elements simultaneously and repeatedly to establish a connection between said pair of elements.

3. The combination in a signaling system of a group of lines, each line having a different designation, means for producing two separate beams of energy, means for driving said beams synchronously to traverse the lines of said group repeatedly, circuit means including said beams for establishing signaling channels between pairs of lines of said group, and means controlled in accordance with the designation of one of the lines of any desired pair to determine the phase relation of said beams for causing them to engage the lines of said pair simultaneously and repeatedly to establish a connection between said pair of lines.

4. The combination in a signaling system of a group of lines, each line having a different designation, means for producing two separate beams of energy, means for driving said beams synchronously to traverse the lines of said group repeatedly, circuit means including said beams for establishing signaling channels between pairs of lines of said group, and means dependent on the designations of both lines of any desired pair for adjusting the space relation of said beams to cause them to engage the lines of said pair simultaneously and repeatedly to establish a connection between said pair of lines.

5. The combination in a signaling system of a group of lines having appearances arranged in a fixed spatial relation, each of said lines having a definite designation, means for producing two movable beams and for driving them synchronously and cyclically over said fixed line appearances, circuit means including said beams for establishing signaling channels between the lines of said group, and means for effecting a time displacement between said beams corresponding to the spatial displacement between any desired pair of lines in said group.

6. The combination in a signaling system of a group of lines having individual appearances arranged in a fixed spatial relation, each of said lines having a different designation, means for producing two movable beams and for driving them synchronously and cyclically over said fixed line appearances, means including said beams for establishing signaling channels between the lines of said group, and means dependent on the designations of the lines of any desired pair for effecting a time displacement between said beams corresponding to the spatial displacement between said pair of lines.

7. The combination in a communication system of a group of lines having appearances arranged in a fixed spatial relation, each of said lines having a different designation number, means for producing two beams of energy and for driving said beams in synchronism over the fixed appearances of said lines, registers for registering the designations of any desired pair of

lines, and means controlled by said registers for effecting a time displacement between said beams of energy corresponding to the spatial displacement between the lines of said pair to cause said beams to engage the lines of said pair simultaneously.

8. The method of establishing a signaling connection between any pair of lines of a group of lines which comprises arranging said lines in a fixed spatial order, causing beams of energy to traverse said lines synchronously and cyclically, and effecting a phase displacement between said beams of energy corresponding to the spatial displacement of the lines of the desired pair.

9. The method of establishing a signaling connection between any pair of lines of a group of lines which comprises arranging said lines in a fixed spatial order, causing beams of energy to traverse said lines synchronously and cyclically, and utilizing the designations of said lines for effecting a phase displacement between said beams of energy corresponding to the spatial displacement of the lines of the desired pair.

10. The combination in a signaling system of a group of elements arranged in fixed spatial relation, means for producing a plurality of beams of energy and for driving them synchronously and cyclically over said fixed elements, means including said beams for establishing signaling connections between said elements, means for introducing phase displacements between said beams for causing them to engage the elements of a plurality of pairs, each pair comprising any element and any desired other element, the engagement of the several pairs occurring cyclically and sequentially and the engagement of the element of each pair occurring simultaneously.

11. The combination in a communication system of a group of lines, a primary beam switch in which said lines appear in a fixed spatial relation, a secondary beam switch in which said lines appear in the same fixed spatial relation, means for driving the beams of said switches in synchronism to scan said lines successively and cyclically, means including said beams for establishing communication connections with said lines, and means for introducing phase displacements between said beams for causing them to engage the lines of any desired pair simultaneously.

12. The combination in a communication system of a group of lines, two beam-producing devices, said lines appearing in a fixed spatial relation in both of said devices, a source of voltage of a given frequency, circuit means for applying voltage from said source to said devices to drive both beams at synchronous speed over said lines in succession and cyclically, and phase-shifting means for shifting the phase of the voltage applied to one of said devices to introduce a desired phase displacement between said beams.

13. The combination in a communication system of a group of lines arranged in fixed spatial relation, means for producing two separate beams of energy, means for driving said beams synchronously to traverse the lines of said group repeatedly, circuit means including said beams for establishing communication connections between said lines, and phase shifters for shifting the phase of one of said beams in opposite senses to introduce a resultant shift in the phase of said beam relative to the phase of the other beam which corresponds to the spatial displacement of any desired pair of lines in said group.

14. The combination in a communication system of a group of lines having designations based on the decimal system, means for producing beams of energy, a source of voltage for driving said beams synchronously to scan the lines of said group, a pair of phase-shifting registers for registering the digital values of the digits in two successive digital places of the designation of any particular one of said lines, means for setting said registers in accordance with the values of the corresponding digits of said particular line, circuit means for applying voltage from said source to said registers in series to effect a shift of phase which is the sum of the shifts produced by said registers, each register serving to shift the phase by an amount proportional to the numerical value of the digit registered thereon, and means for changing the frequency of the voltage applied to one of said registers with respect to the frequency applied to the other register by an amount which corresponds to the difference in decimal value between the successive decimal places to which said registers correspond.

15. The combination in a communication system of a group of lines having designations based on the decimal system, means for producing beams of energy, a source of voltage for driving said beams synchronously to scan the lines of said group, a pair of phase-shifting registers for registering the digital values of the digits in two successive digital places of the designation of any particular one of said lines, means for setting said registers in accordance with the values of the corresponding digits of said particular line, circuit means for applying voltage from said source to said registers in series to effect a shift of phase which is the sum of the shifts produced by said registers, each register serving to shift the phase by an amount proportional to the numerical value of the digit registered thereon, means for multiplying the frequency of the voltage applied to a particular one of said registers by a factor representing the difference in decimal value between the digital place to which said register corresponds and the digital place to which the other of said registers corresponds, and means for dividing by the same factor the frequency of the voltage after it has experienced the shift of phase imposed by said particular register and before it is applied to said other phase-shifting register.

16. The combination in a communication system of a plurality of lines, a common medium having communication channels, one between each line of said plurality of lines and each other line of said plurality, beam switches in which the channels of said common medium appear, means for driving the beams of said switches synchronously over said channel appearances, and means controlled by any particular one of said lines for shifting the phase relation between said beams to select the communication channel of said common medium which interconnects said particular line and any other desired one of said lines.

17. The combination in a communication system of a plurality of lines, a common medium having communication channels, one between each line of said plurality of lines and each other line of said plurality, beam switches in which the channels of said common medium appear, means for driving the beams of said switches synchronously over said channel appearances, and means controlled by any number of said lines as calling lines for varying the phase relation between said synchronous beams to select the communication channels which interconnect said calling lines

respectively with a corresponding number of said lines chosen at will as called lines for concurrent communication.

18. The method of interconnecting any pair of lines of a plurality of lines over a common transmission medium which consists in establishing in said medium recurrently and in rapid succession time-separated transmission channels individual respectively to said lines and shifting the position of any one of said channels in time to coincide with the time position of any other one of said channels.

19. The method of interconnecting any pair of stations of a plurality of stations over a common transmission medium which consists in establishing in said medium recurrently and in rapid succession time-spaced transmission channels individual respectively to said stations, and shifting the position of any one of said channels in time to coincide with the time position of any other one of said channels.

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