Oct. 17, 1939. H. J. NICHOLS 2,176,680

COMMUNICATION SYSTEM

Filed April 2, 1936 6 Sheets-Sheet 1

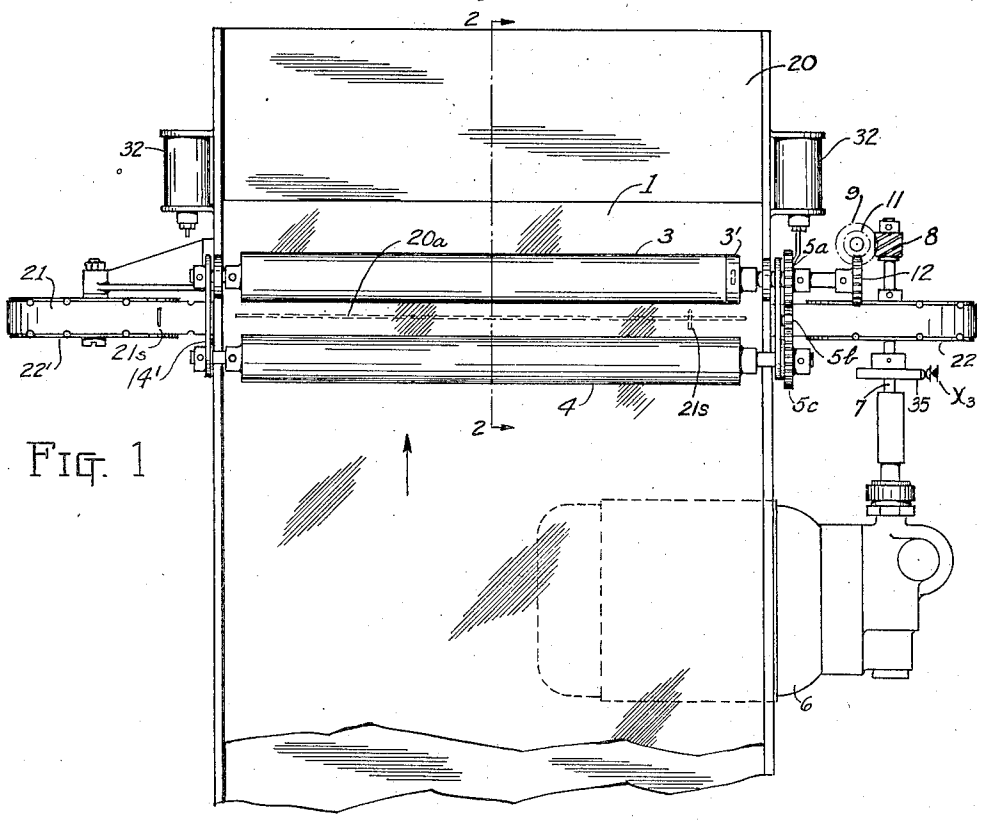


FIG. 1

FIG. 2

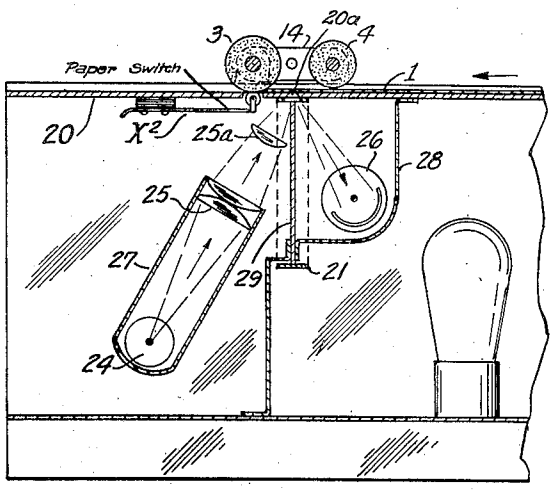
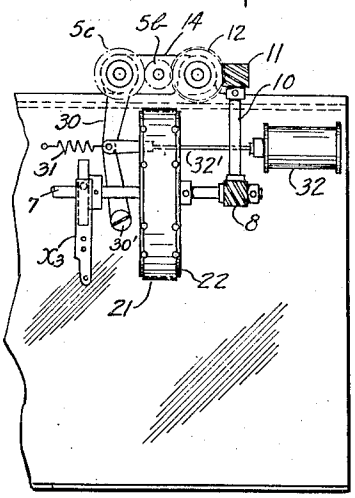


FIG. 2A



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COMMUNICATION SYSTEM

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FIG. 3

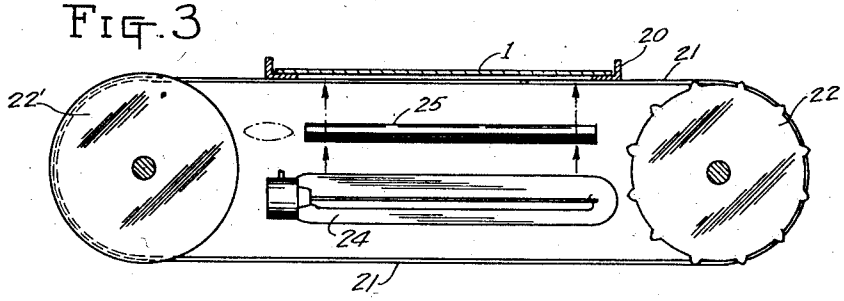


FIG. 4

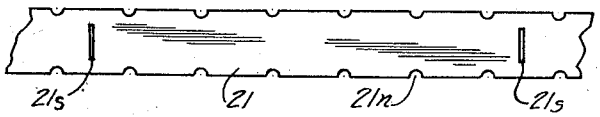


FIG 5

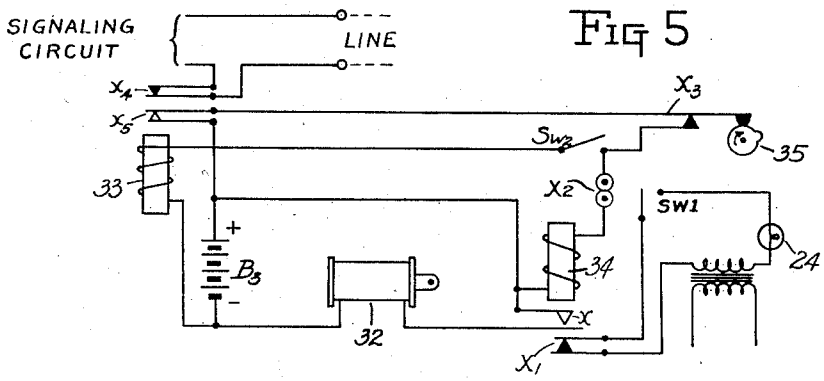
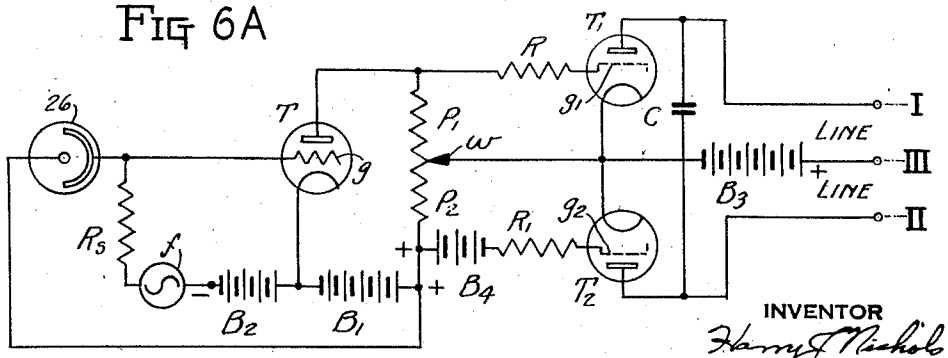


FIG 6A



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FIG. 6

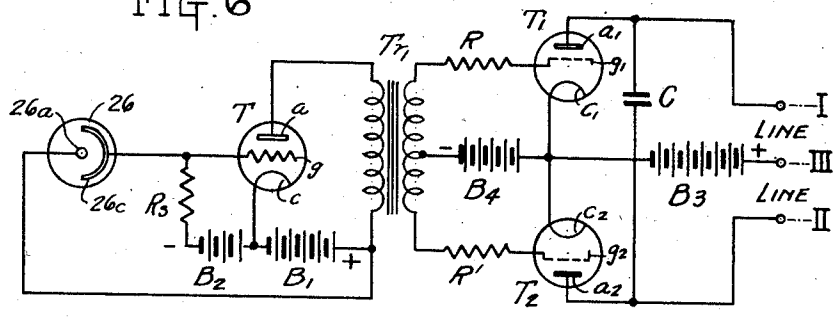


FIG. 12

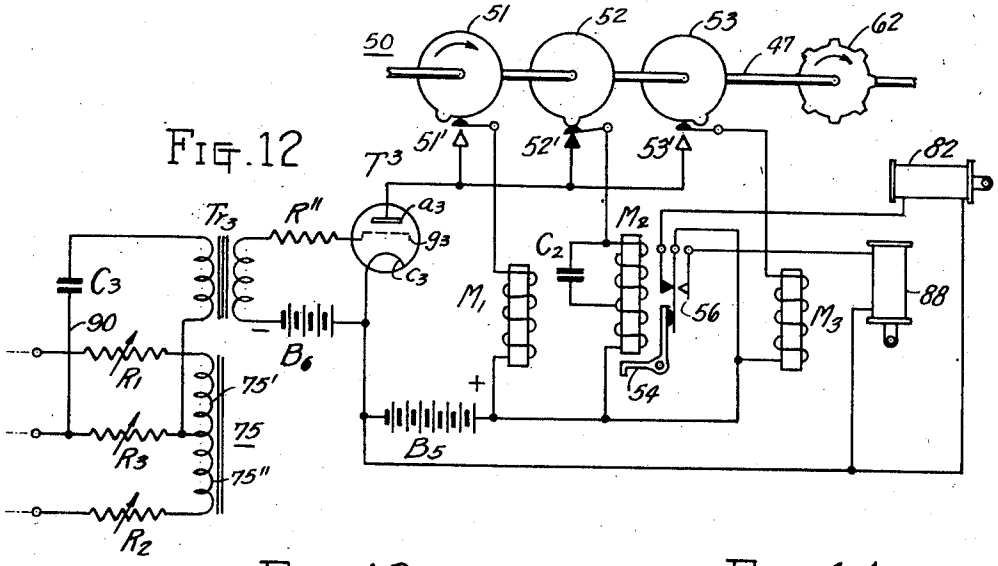


FIG. 13

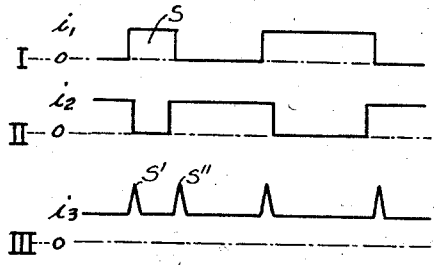


FIG. 14



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FIG. 7

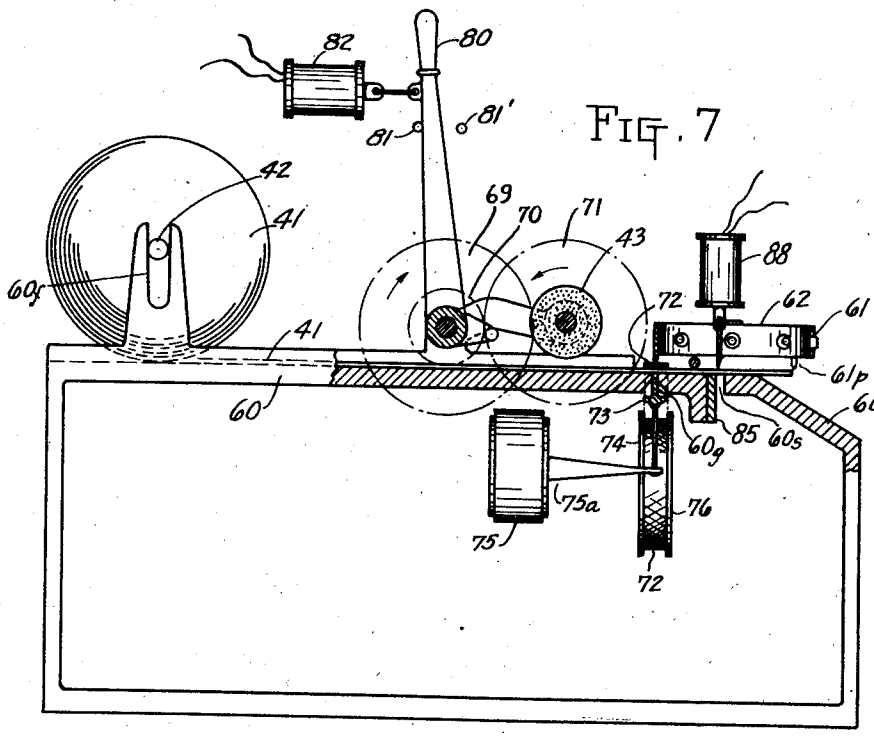
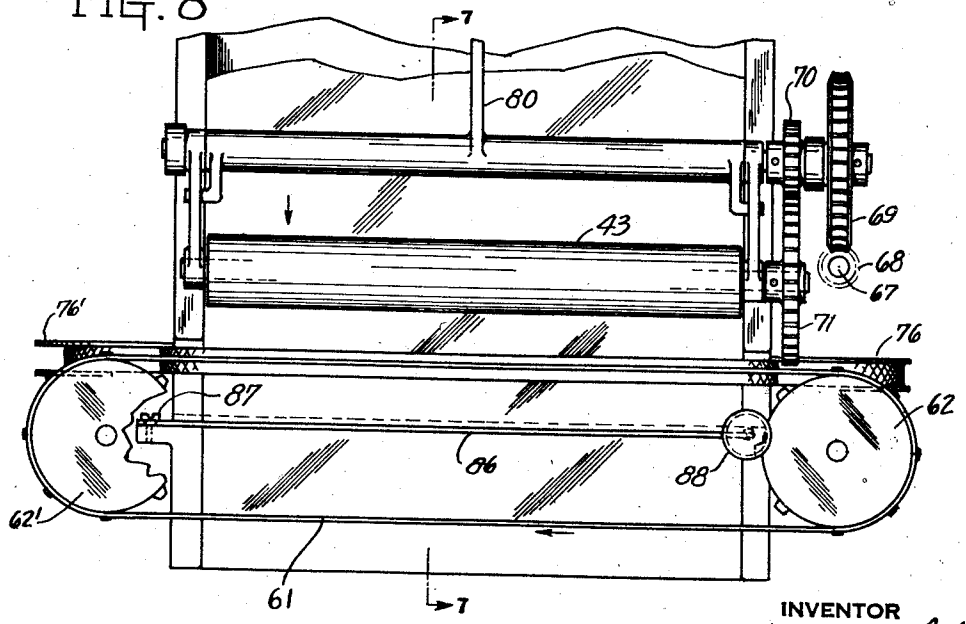


FIG. 8



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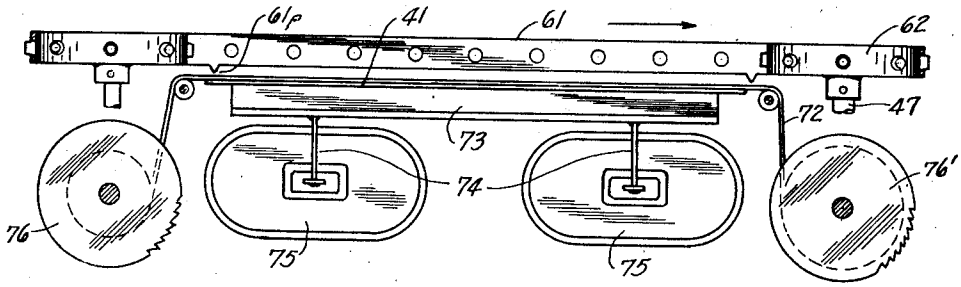


FIG. 9

FIG. 10

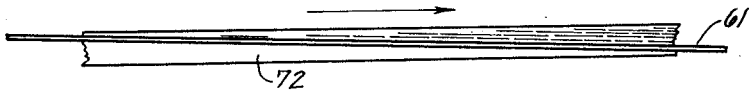


FIG. 11

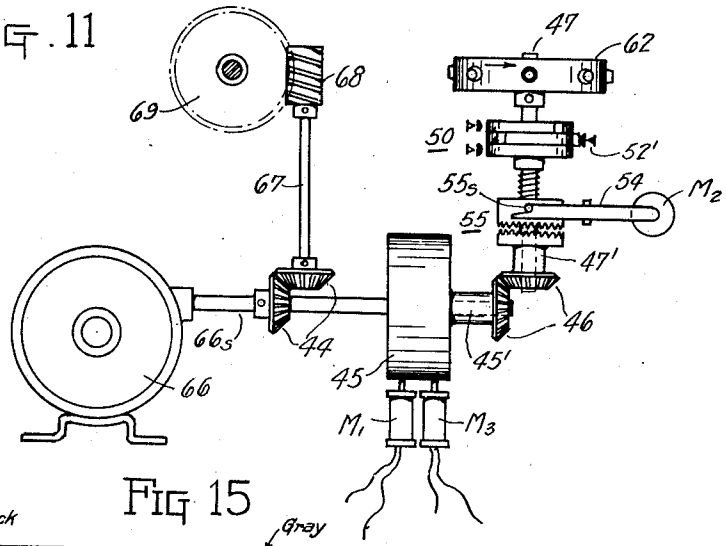
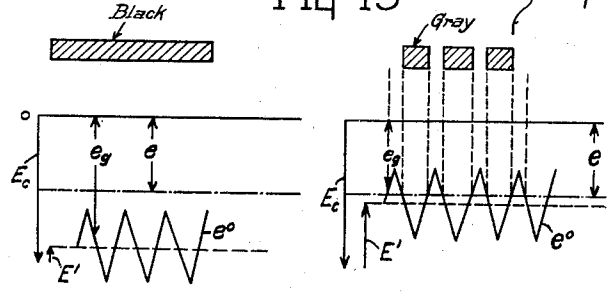


FIG 15



$e_g = -E_c + E' + e^\circ$

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COMMUNICATION SYSTEM

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FIG. 16

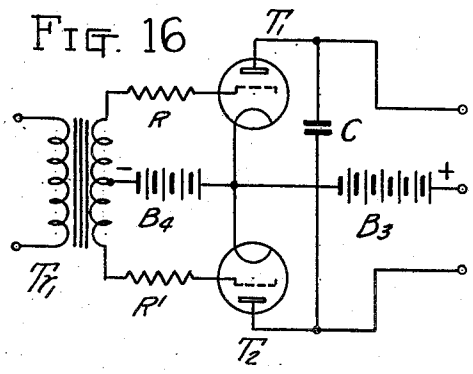


FIG. 17

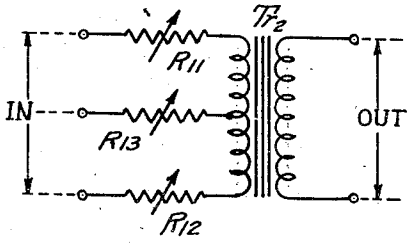


FIG. 19

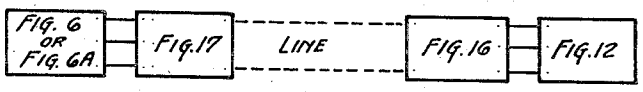


FIG. 20

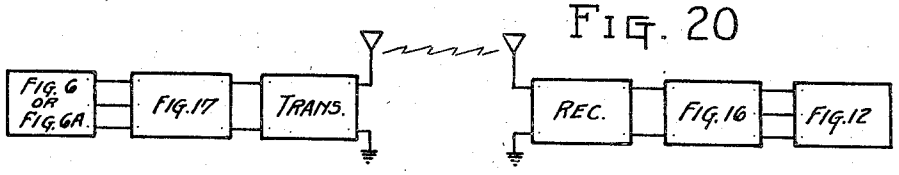
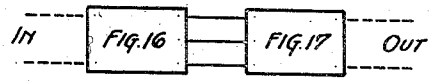


FIG. 18



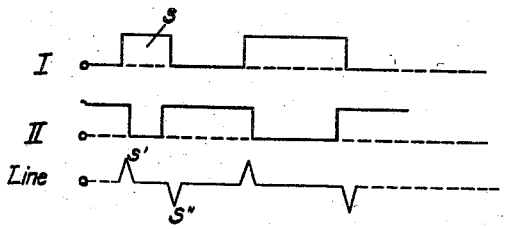


FIG. 21

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Patented Oct. 17, 1939 2,176,680

UNITED STATES PATENT OFFICE

2,176,680

COMMUNICATION SYSTEM

Harry J. Nichols, Binghamton, N. Y., assignor to International Business Machines Corporation, New York, N. Y., a corporation of New York

Application April 2, 1936, Serial No. 72,349

13 Claims. (Cl. 178—11)

This invention relates to a communication system, and in particular to facsimile transmission systems and the like.

The principal object of my invention is to provide a simple and highly satisfactory system for the transmission of graphic material such as pictures, writing, printing, documents and the like over various types of communication systems.

Another object is to provide a facsimile system characterized by simplicity and low cost, that shall be inexpensive and easy to operate and to keep in order, and free from complications in its operation.

It is also an object of this invention to provide improved systems of this character adapted to record and reproduce in full tone, that is, in black and white, and also adapted to record and reproduce in half-tone, where a range of shades from white through gray to black are obtained.

A further object is to provide an improved scanning means and a novel paper control apparatus so that the procedure in preparing copy for transmission and in starting the transmission is made very quick and simple.

A further object is to provide a facsimile system of this character in which the graphic original is reproduced on plain paper, thus avoiding the expense and trouble incident to photographic and chemical methods of reproducing.

A further object is to provide a simplified facsimile transmission system which does not require carrier waves or currents, avoiding the necessity of demodulating or rectifying the received signals, and in which only a limited frequency band is required, thus facilitating transmission over ordinary communication circuits.

It is a still further object to provide an improved and simplified method of facsimile transmission.

Other objects and advantages will be obvious in connection with the following description, the accompanying drawings, and the appended claims.

In the drawings:

Fig. 1 is a fragmentary plan view of one embodiment of apparatus constructed in accordance with the present invention;

Fig. 2 is a fragmentary sectional view on the line 2—2 of Fig. 1;

Fig. 2A is a fragmentary side elevational view of the apparatus shown in Fig. 1;

Fig. 3 is a schematic illustration of the scanning arrangement forming part of the invention;

Fig. 4 is a detailed view of a section of the scanning belt forming part of the arrangement of Fig. 3;

Fig. 5 is a schematic diagram of the control circuits for the transmitter;

Fig. 6 is a schematic diagram of the signal generating and transmitting circuits of the transmitter;

Fig. 6A is a similar diagram showing an adaptation of the invention to a half-tone process;

Fig. 7 is a representation, in part section on the line 7—7 of Fig. 8, of one form of recording apparatus involving my invention;

Fig. 8 is a fragmentary plan view of the apparatus of Fig. 7;

Fig. 9 is a schematic illustration of the recording arrangement forming part of the invention;

Fig. 10 is a detailed view showing the preferred motional relationship of the recording belt and the recording ribbon;

Fig. 11 is a schematic illustration of the drive means for the recording apparatus of Fig. 7;

Fig. 12 is a schematic diagram of the signal receiving and control circuits of the recording apparatus;

Fig. 13 is a diagram illustrating the nature of typical received picture and synchronizing signals;

Fig. 14 is a diagram illustrating the action of the armature of the magnetic recording unit;

Fig. 15 is a diagram showing in exaggerated graphic form the potentials applied to the photocell amplifier, and the resulting recordings;

Fig. 16 is a schematic circuit diagram of a signal-converter unit;

Fig. 17 illustrates diagrammatically a converter coupling unit whereby alternative direct current impulses may be converted into representative line signals;

Fig. 18 illustrates the combination of the arrangements shown in Figs. 16 and 17 to form a signal repeater unit;

Fig. 19 illustrates the combination of apparatus to constitute a long-line facsimile system;

Fig. 20 illustrates the combination of certain apparatus to constitute a radio facsimile system; and

Fig. 21 is a diagram illustrating the nature of the synchronizing and picture signals sent to the line by the converter coupling unit shown in Fig. 17 in conjunction with the transmitting arrangement shown in Fig. 6.

In the various figures, like characters represent like parts.

Referring first to Figs. 1, 2, and 2A, wherein the sending apparatus is shown in more or less

diagrammatic form for convenience in illustration and description, the record to be transmitted is represented by the sheet of paper 1, termed the record sheet, which is assumed to be placed face downward on the table 20 of the sending apparatus. The record sheet is slid along the table from right to left as viewed in Fig. 2 until registered in position over the scanning slot 20*a* when the leading edge (ordinarily the top edge) of the sheet reaches the position of engagement with feed roller 3, auxiliary roller 4 being lifted slightly to enable the record sheet to pass under it freely. During the scanning process, the record sheet is moved continuously across the scanning slot at a suitable slow rate by paper feed mechanism including feed roller 3 and auxiliary roller 4 driven therefrom by suitable means as for example spur gears 5*a*, 5*b*, 5*c*. Gear 5*b* is an idler gear and is rotatably mounted on link 14. Gears 5*a* and 5*c* are preferably similar so that the angular speeds of the feed roller and auxiliary roller are the same. Auxiliary roller 4 may if desired be made slightly smaller than feed roller 3, so that its peripheral speed is slightly less, thereby exerting a slight stretching action on the record sheet, so that the sheet is held taut and flat against the table to assure close contact of the record sheet with scanning slot 20*a*. The edges of slot 20*a* may also be slightly raised above the level of the table to secure close contact with the record sheet at this point.

The rollers are driven at suitable speed by drive motor 6, operating through a transmission arrangement comprising drive shaft 7, worm 8, gear 9, shaft 10, worm 11, and gear 12 the last being fixed on the axle of feed roller 3. Rollers 3 and 4 may be of yielding frictional material such as rubber or cork, or may be metallic cylinders with roughened drive surfaces. Auxiliary roller 4 is held in proper position relative to feed roller 3 by links 14, 14', which links pivot about the axle of feed roller 3, thus permitting auxiliary roller 4 to be raised clear of the table without disturbing the relations of the gear train. Auxiliary roller 4 is raised by solenoid 32, which upon energization and by means of link 32' actuates toggle pair 30, supported at pivot 30'. A tractile spring 31 returns toggle 30 to unoperated position whereby roller 4 is lowered in position upon cessation of the pull of solenoid 32. Solenoid 32 is controlled by a control circuit described hereinafter. Feed roller 3 is preferably provided with a metallic ring 3', slightly smaller in diameter than the frictional cylinder, which cooperates with paper switch X2 in the operational control function. Ring 3' closes the contacts of switch X2 in the absence of a sheet of paper on the scanning table, but as soon as a sheet passes under the roller, the circuit is opened.

The scanning arrangement is shown in Figs. 2, 2*a*, and 3. A scanning belt 21 is suitably positioned underneath table 20 and is positively driven by sprocket wheel 22, preferably mounted on the shaft 7 of motor 6, and is held taut in position by idler wheel 22'. A light source 24, preferably in the form of an elongated incandescent lamp, is mounted in proper position relative to the orbit of belt 21 by suitable means not shown, and its light is concentrated obliquely by condenser lens system 25, 25*a* so as to project a bright converging band of light on the inner side of the upper section of the scanning belt. Referring to Fig. 4, scanning belt 21 is provided with drive notches 21*n*, and with equally spaced scanning slits 21*s* whose spacing longitudinally of the belt is substantially the width of the widest record sheet for which the machine is designed. The scanning slits have a width substantially equal to the elements into which the record is to be resolved, but are preferably elongated transversely to enable light to be projected on the record surface and to be reflected diffusely therefrom to photo-cell 26. The lens system 25 is such that the light passing therethrough is converged and focused substantially at the surface of the element to be scanned. The scanning belt is located between the lens system and the line of focus, and the elongated slit thus provides for the passage of the desired light beam to and from the scanning point. The band of light from the light source at other points along its length is shut off from the photo-cell by the cooperation of the scanning belt and baffle 29, which is substantially in contact along its upper edge with the scanning belt. Thus the light reaching the photo-cell is substantially restricted to that reflected from the elemental area illuminated at the scanning point.

The light rays impinging on the record surface at the scanning point are reflected away at an angle, following well known optical laws, the diffused light reaching a light reactive device 26, such as a photo-cell or the like. Suitable shielding is provided, including hoods 27 and 28 and baffle 29, to prevent extraneous light affecting the operation of the photo-cell 26. The light and optical arrangements are such that as a scanning slit 21*s* moves along, a bright spot of light of the size of the basic photo-element traverses the record sheet, and light in varying amounts is reflected to the photo-cell as the record sheet is scanned. The paper is meanwhile moved slowly and continuously by the paper feed mechanism, the speed ratio between the scanning belt and the paper feed preferably being such that the paper progresses one elemental line for each traverse of a scanning slit. The record is thus systematically analyzed line by line and element by element, as will be readily understood, the light variations received by the photo-cell being substantially proportional to the light and shade values of the record. These light variations are converted into electrical signals, generally known as picture signals, by transmitting means described hereinafter.

Referring now to Figs. 2, 2*a*, and 5, operating control of the scanning apparatus and of the transmission of signals is provided by a control arrangement comprising paper switch X2, cam switch X3, control relays 33 and 34, and the controlled elements comprising solenoid 32, light source 24, and the signalling circuit. Relay 33 is provided with contacts X4 adapted to control the signalling circuit, and with contacts X5 which are in an auxiliary circuit including cam switch X3. Relay 34 is provided with contacts X adapted to control solenoid 32, and with contacts X1 controlling light source 24. Light source 24 may be conveniently energized by power transformer 36 as shown, or by any other suitable source of power.

The sending operation is started as follows: Let it be assumed that power is connected to motor 6, hence that the feed mechanism is driven at proper speed. Switches *Sw1* and *Sw2* are then closed, the former connecting power to light source 24, the latter energizing relays 33 and 34. The contacts of these relays are shown in unoperated position in Fig. 5; thus when these relays are energized, contacts X energize solenoid

32, contacts X1 interrupt the current to light source 24, contacts X4 disconnect the signalling circuit, and contacts X5 place cam switch X3 in circuit with the winding of relay 33. When energized, solenoid 32 causes feed roller 4 to be raised clear of table 20 as previously described.

To start scanning, the record sheet 1 is slid along table 20 until it is engaged by feed roller 3 which thereafter advances the record sheet gradually (see Fig. 2). As soon as the sheet passes under roller 3, paper switch X2 is opened and current is cut off relay 34 which is thus deenergized, causing contacts X to open and contacts X1 to close, thereby deenergizing solenoid 32 and applying current to light source 24. Solenoid 32 releases its pull on toggle lever 30 and the toggle pair is "broken" at the hinge joint by the pull of retractile spring 31 lowering auxiliary roller 4 until its weight rests upon the record sheet. Cam 35 of the cam switch continues to rotate, and shortly before a slit of scanning belt 21 reaches the end of scanning slot 20*s*, contacts X3 are opened by the rise on cam 35, removing current from relay 33 and deenergizing same. Contacts X4 are thus caused to close at the point in the scanning cycle where the periodic synchronizing signal is being generated, and since the signalling circuit is connected to the line by the closing of contacts X4, the first signal transmitted to the line is a synchronizing signal. Contacts X5 open upon the deenergizing of relay 33, hence subsequent closing of the circuit by cam switch X3 is ineffective, and the control circuits remain unresponsive until control is subsequently regained by paper switch X2. Meanwhile, periodic synchronizing signals and picture signals are permitted to pass to the line.

The sending machine continues the scanning until the record sheet has been fed beyond the point of application of paper switch X2 whose contacts are permitted to close, reversing the starting procedure by applying current to relays 33 and 34. These in turn interrupt the sending of signals to the line, cut off current to the light source, and energize solenoid 32, the latter raising feed roller 4 to permit the entry of another record sheet. Feed roller 3 continues to advance the previous record sheet until it is free to drop into a receiving pocket (not shown).

It will be noted that the arrangement shown provides for automatic start under control of the record sheet and automatic shut-off. The control elements shown may, however, be combined in various ways as desired.

Referring next to Figs. 7, 8 and 9 showing one embodiment of a recorder apparatus according to the invention, the recorder mechanism is mounted on a frame including table 60. A roll of paper 41, on which the subject matter is to be recorded, is mounted on an axle 42 moving vertically between two forked guide members 60*f*. The paper feed mechanism comprises feed roller 43 for feeding the paper continuously past the recording point. Bell-crank control lever 80 is adapted to raise and lower roller 43, and is automatically actuated by solenoid 82. Feed roller 43 is driven from drive motor 66 (see Fig. 11) by a transmission arrangement including drive shaft 67, worm 68, worm gear 69, pinion 70 and gear 71, the latter being fixed on the axle of feed roller 43. No auxiliary feed roller is necessary; otherwise the paper feed arrangement may be substantially the same as that at the transmitter.

A suitable reproducing arrangement, whose general function is the reverse of the scanning arrangement at the sender, includes recording belt 61 mounted above the table and provided with stylus points 61*p* spaced longitudinally of the belt a distance corresponding to the spacing of the scanning slits 21*s* at the sender. Belt 61 is positively driven by sprocket wheel 62 and is held taut in position by idler wheel 62'. The edge of the recording belt moves transversely across the paper along the median line of a narrow guide slot 60*g* extending partly across table 60, this slot corresponding to the scanning slot 20*a* at the sender. A light but rigid pressure bar 73 of inverted T-section and somewhat shorter than the width of the paper moves freely in guide slot 60*g*, and is mounted on and driven by the armature pieces 75*a* of one or more magnetic motor units 75 (two being shown). These armature pieces, extended at right angles by thrust rods 74, reciprocate pressure bar 73 in response to printing signals which in turn presses the paper against the recording belt as required in the reproduction process. The actual recording is preferably done by means of an inked ribbon 72 stretched taut across and above the paper along the path of traverse of the stylus points 61*p*, altho other recording media such as a carbon paper and the like, may be used. The paper and ribbon are squeezed between the pressure bar and stylus point. The recording belt thus acts as the anvil or platen, while the pressure bar acts as the hammer. The ribbon is fed slowly along its length from reel 76 to reel 76' and vice versa by ribbon feed mechanism (not shown). This ribbon feed mechanism may be any one of numerous ribbon feed mechanisms commonly used on typewriters, hence need not be described in detail.

The preferred arrangement of the inked ribbon with reference to the recording line of the stylus points 61*p* is for the ribbon to be positioned so that the stylus points move diagonally from margin to margin of the ribbon. The preferred arrangement is shown in Fig. 10, and referring thereto it will be noted that the stylus points move so as not to catch the edges of the ribbon. The combined motions of the stylus points and ribbon, which latter is moved at such a rate that it is advanced substantially one line width for each traverse of a stylus point, cover the entire surface of the ribbon much in the same manner that the stylus points are caused to cover the surface of the paper. In this way, a fresh inked surface of the ribbon is presented to each succeeding stylus point, and all the surface and ink of the ribbon are effectively used in the reproduction process.

Referring again to Figs. 7 and 8, the reproducer is also provided with mechanism to automatically cut the strip of paper into sheets of message size. A shear edge 85 is mounted in a shear slot 60*s* located in the table 60 at such distance from guide slot 60*g* as to provide the desired top and bottom margin on the message sheet. A shear knife 86, pivotally mounted on hinge pin 87 at one edge of the table, forms a scissors pair with shear edge 85, which pair is normally held closed by the weight of the shear knife. Attached to the free end of the shear knife is a lifting solenoid 88, normally unenergized, but which when energized lifts the shear knife so as to permit the passage of the strip of paper underneath the shear edge. When solenoid 88 is de-energized, shear knife 86 is dropped and its weight is sufficient to cut through the

paper strip, thus detaching a sheet bearing the previous recording.

Referring now to Fig. 6 which shows diagrammatically the apparatus at the sending station for generating and transmitting the synchronizing and picture signals, which apparatus will be called the transmitter, photo-cell **26** may be of any suitable type, a photo-tube having a photo-emissive cathode 26*c* and a concentrated anode 26*a* being shown in conventional representation. The current variations in photo-tube **26**, being usually of a feeble nature, are amplified by amplifier tube T, which may be the usual triode vacuum type having a hot cathode *c*, plate or anode *a*, and control grid *g*. Battery B1 provides the plate potential for tube T, battery B2 a normal negative bias to the control grid, while both batteries provide an accelerating potential for photo-tube **26**. Resistor Rs serves as a grid resistor for tube T, and as a current limiting resistor for photo-tube **26**. Tube T works into transformer Tr1 which is provided with a center tapped secondary adapted to apply opposing potentials to electronic relays T1 and T2, connected in the well known push-pull arrangement.

While electronic relays T1 and T2 may be of various types, the preferred type is a gaseous triode comprising a hot cathode, a control grid, and an anode or plate; all mounted in a sealed glass envelope containing an atmosphere of gas or vapor. Triodes of this type provide the advantages of ease of control, large current carrying capacity, quick response, and a high ratio of power controlled to control power. The grid of the typical gaseous triode can initiate ionization, but thereafter loses control, and some means for reducing the plate voltage below the de-ionization potential must be employed to assist the grid in terminating the ionization current. The two electronic relays T1 and T2 are arranged to operate as an inverter, their input circuit being coupled to the output circuit of tube T by means of transformer Tr in such manner that T1 and T2 operate alternately in response to increase and decrease of current flow in the plate circuit of T. The output of T1 and T2 is connected to a two-circuit three-wire line, or equivalent, whereby the current variations in T1 and T2 are transmitted to the receiving station. The anodes *a*1, *a*2 of T1 and T2 are directly connected by capacitor C which aids in the inverter action. In connection with this arrangement, it should be observed that photo-cell **26** functions to translate light variations into proportional electrical variations, while tube T merely amplifies these variations. Electronic relays T1 and T2 with their associated circuits function, however, to convert the electrical variations of amplifier tube T into timed signals capable of being transmitted and interpreted for recording purposes.

Referring now to Fig. 12, at the receiivng station, the line signals from both line circuits are connected to the windings of magnetic unit **75**, preferably through variable resistors R1 and R2 and R3. These resistors could be placed in the line at some other point, as for example in the circuits at the sending station, but it is usually more convenient to have them at the receiving station inasmuch as they provide a convenient means of balancing the line circuits, to adjust the signal level, and to make other adjustments affecting the process of reproduction. For reasons presently to be developed, it is advantageous to apply the line currents to the windings of unit **75** in the form of direct currents.

Unit **75** is preferably provided with a center tapped, balanced winding as indicated, although other types of windings and connections may be employed. When more than one unit is used, the same types of winding should be used, the sections being connected in series or parallel, hence a plurality of units may be regarded as one unit. Across resistor R3, connected in the center or ground leg of the transmission line, is shunted an auxiliary circuit **90** including capacitor C3 and the primary of transformer Tr3. Due to the blocking action of C3, this circuit does not pass direct current, but responds only to current changes in the middle line.

Electronic relay T3, similar in character to T1 and T2, has an input circuit including the secondary of transformer Tr3, connected on one side to the grid *g*3 via suppressor resistor R'', on the other side to bias battery B6, thence to cathode *c*3. The output circuit of T3 includes battery B5 and a plurality of parallel circuits connected in circuit by a rotary contactor **50** comprising cams **51**, **52**, and **53** with their associated contacts **51'**, **52'** and **53'**. These cams are preferably mounted on the same shaft with sprocket wheel **62** as indicated.

Corrector magnets M1 and M3 are connected in the branch circuits including contacts **51'**, and **53'**, respectively. Clutch magnet M2 is connected in the branch circuit including contacts **52'**. Clutch magnet M2 is of quick acting, slow release type, capable of being sustained in operation by periodic impulses, energy being stored in capacitor C2 to keep the winding energized between impulses. Clutch magnet M2 is provided with pawl member **54** which actuates clutch **55** (see Fig. 11) ad also with make-break contacts **56** which connect solenoids **82** and **88** alternately into circuit with battery B5, solenoid **82** being connected when M2 is deenergized and solenoid **88** when M2 is energized. The functions of the various elements of the receiving and control circuits will be more fully disclosed in the description of the operation of the recorder.

Referring again to Figs. 1, 2, 2*a*, 5, and 6, the operation of the sending arrangement is as follows: Assuming that power has been turned on the transmitter and the motor is running at normal speed, the record sheet is advanced along table **20** manually until engaged by feed roller 3, starting the paper feed as previously described. As scon as the record sheet opens the contacts of paper switch X2, relay **34** is deenergized, contacts X1 thereof applying current to light source **24**. Where a white or blank margin exists at the top and bottom of a record sheet, as light scurce **24** illuminates, the light passes through a scanning slit of moving belt **21** and is reflected toward photo-cell **26** which receives a steady light. When the scanning belt **21** reaches an underlap position, (in wh'ch no slit lies in the light path), light is cut off from photo-cell **26**, whereby the current therethrough is abruptly diminished. This current change is amplified in the plate circuit of tube T, and an impulse is transmitted to electronic relay T1 through transformer Tr1, causing electronic relay T1 to be tripped. When the slit emerges into a light transmitting position, full light reaches photo-cell **26**, abruptly increasing its current, thereby producing an impulse in transformer Tr1 in the opposite direction and tripping electronic relay T2. When T2 starts to discharge, capacitor C which was previously charged during the discharge of T1, is subject to a sudden lowering of the potential at its terminal connected to anode *a*2, causing a sudden drop of potential at anode *a*1. By reason

of this drop and the current lag caused by the impedance in the line circuits, the voltage in the plate circuit of T1 is momentarily reduced below the deionization potential, permitting T1 to become deionized and grid *g1* to regain control. The voltage applicable to the grid being below the point required for ionization however, the tube remains blocked.

When the scanning slit reaches the succeeding underlap position, current in Tr1 again reverses, applying a tripping potential to the grid of T1 and a blocking potential to the grid of T2. T1 is again tripped, and the process is reversed interrupting the current flow through T2. Thus it is seen that once an electronic relay is tripped. current continues to flow therethrough until the other relay starts to discharge, whereupon the current in the first tube is interrupted. It should be noted that the currents in the outer conductors of the line alternate, but that current flows in the middle conductor when either T1 or T2 is conducting.

From the above description, it is apparent that a current pulse of uniform character is sent to the line during each underlap interval. This periodic signal may be used as and preferably constitutes the synchronizing signal.

Assuming next that the record sheet has progressed to the point where its subject is being scanned, it should be clear from the analysis of the generation of synchronizing signals that as a scanning slit passes from a dark to a light portion of the scanned area, electronic relay T2 will be made conducting, and will remain conducting while such light portion is being scanned, but upon traversing a dark area, electronic relay T1 alone will pass current to the line. Thus the duration of the signals sent to the line alterately by T1 and T2 will represent the dark and light areas respectively of the subject. The roles of T1 and T2 can of course be readily transposed by reversing connections in various parts of the circuits, whereby T1 will represent the light and T2 represent the dark areas of the subject. The variable length signals sent by T1 and T2 thus constitute the picture signals.

From the foregoing, it is apparent that the picture signals are direct current signals of uniform amplitude, being characterized by their time of occurrence relative to the periodic synchronizing signals and by their duration. Thus reproduction will be in two contrasting shades without intermediate shades, that is in full tones. It is readily possible, however, to adapt the invention to the production of half-tone effects, as will be explained hereinafter.

In order to assure the sending of proper synchronizing signals at each underlap position it is desirable to provide a margin on the subject being scanned of light reflecting properties. Thus as the scanning of the subject is completed a marginal light reflective area will be encountered in the scanning operation which will assure the operation of the light source to send a synchronizing pulse at the underlap position. Only a narrow margin need be provided for this purpose.

Referring now to Fig. 11 which shows in somewhat schematic manner the driving and synchronizing arrangement of the recorder, drive shaft 67 is driven from motor shaft 66S by means of bevel gear 44, and through a system of gears drives paper feed roller 43. Phase corrector mechanism 45 is mounted on shaft 66S. This mechanism may be of any desired type capable of selectively advancing or retarding the phase position of the controlled member as required to bring it into synchronous operation with the synchronizing impulses. A mechanism suitable for use in connetcion with the present invention is shown in my copending patent application Serial No. 736,383 filed July 21, 1934. As shown, the mechanism comprises a pair of corrector magnets M1 and M2, one adapted upon energization to increase the speed of the controlled member, sleeve 45', with respect to its drive shaft 66S, and the other adapted to decrease the speed thereof. Sleeve 45', controlled by the phase corrector mechanism and rotatable thereby with respect to drive shaft 66S, drives a second sleeve 47' through bevel gear 46. A clutch 55, of positive type, couples sleeve 47' to auxiliary shaft 47 under the control of clutch magnet M2. Pawl member 54, actuated by magnet M2, has a diagonally slanting end piece ending in a notch adapted to intercept stop pin 55S, thus disengaging the clutch coupling members and bringing shaft 47 to a stop in predetermined angular position. In this position, rotary contactor 50, whose cam members are fixed on shaft 47, stops in such position that contacts 52' are closed. (See Fig. 12.) Drive sprocket 62 is also fixed on shaft 47, hence movement of recording belt 61 is coordinated with the cam members in such relation that one of the stylus points is in the underlap position during that portion of a cycle of operation when contacts 52' are closed. The arrangement is such that the recorder is stopped in and released from a predetermined initial position whereby approximate synchronism is established in response to the first received synchronizing signal. More exact synchronism is effected and thereafter maintained by the phase corrector arrangement as described below in connection with synchronization.

Referring now to Figs. 11 and 12, the operation of the receiving apparatus in utilizing the synchronizing signals is as follows: In stand-by condition, clutch magnet M2 is not energized, permitting pawl member 54 to intercept stop member 55S of clutch 55, disengaging same and stopping cam shaft 47 in a predetermined angular position. In this position, cam 52 closes its contacts 52' as indicated in Fig. 12.

When the transmitter sends the first synchronizing signal, a current change occurs in the middle conductor of the line, hence a voltage drop develops across resistor R3, causing a current pulse in auxiliary circuit 90 including the primary of transformer Tr3. The secondary of Tr3 applies a positive swing to grid *g3* of electronic relay T3, overcoming the bias and tripping T3 which thereupon becomes conducting, grid *g3* losing control. Current flows from the positive side of battery B6 through the winding of M2 (and capacitor C2 in shunt with part of the winding) via contacts 52' and T3 back to battery, energizing M2 and leaving a charge stored in capacitor C2. Magnet M2 is quick acting, hence actuates pawl 54 quickly, permitting clutch 55 to engage with very little delay thus connecting driving power to sprocket wheel 62. When contacts 52' open by reason of the rotation of cam 52, relay T3 is deionized, grid *g3* meanwhile having been restored to normal bias by battery B6 and regaining control. The charge stored in capacitor C2 is sufficient to hold magnet M2 operated for several revolutions of sprocket wheel 62. Because of the slight delay incident to the operation of magnet M2 and clutch 55, the cam shaft may lag slightly and thus when the

second synchronizing signal is received, contacts 51' of cam 51 are closed. T3 is tripped by the synchronizing signal as before, but this time the discharge current flows through corrector magnet M1 via contacts 51'. Magnet M1 actuates phase corrector 45 to advance the phase, regaining part or all of the initial lag. Phase correction is repeated on succeeding synchronizing signals, if necessary, until unison is established, whereupon the local synchronizing pulses are applied to clutch magnet M2, sustaining same in operated condition.

Thereafter, should the receiving apparatus tend to lag relative to the synchronizing signals, corrector magnet M1 is energized, advancing the phase to restore unison; should the receiving apparatus tend to lead, corrector magnet M3 is energized, retarding the phase to restore unison. Recording belt 61, sprocket wheel 62, cam shaft 47 and rotary contactor 52 are motionally coordinated in such manner that when contacts 52' close coincidentally with the period of the local synchronizing pulses, recording belt 61 moves in unison with scanning belt 21 at the transmitter. Without further analysis, it should be clear that the periodic synchronizing signals are first utilized to establish synchronism, and are thereafter utilized to maintain synchronism.

When clutch magnet M2 is operated, the break contacts of switch 56 remove holding current from solenoid 82 thus starting the paper feed, while the make contacts apply holding current to solenoid 88, raising shear knife 86, permitting the paper to feed beyond the shear point. At the end of the transmission, when the synchronizing signals cease, magnet M2 is deenergized, and consequently solenoid 82 is reenergized, stopping the paper feed, while solenoid 88 is deenergized, dropping shear knife 86 which cuts the message sheet from the strip of paper.

The manner in which the picture signals are utilized in reproduction is as follows: Assume now that recording belt 61 has been synchronized with the transmitter as described above. As the picture signals are received from the line, current passes through the windings of magnetic unit 75 in alternate directions. Assuming again that current flows through tube T2 when light portions of the subject are being scanned, and through T1 when the dark portions are being scanned, corresponding currents will flow through windings 75' and 75'' of unit 75. Unit 75 is provided with resilient centering means (not shown) whereby armature 75a tends to return to mid position when displaced therefrom. (See Fig. 7.) When current flows through winding 75'', armature 75a pulls pressure bar 73 away from the paper, and when current flows through winding 75', thrusts it towards the paper, while in normal position, pressure bar 73 has its upper edge substantially in contact with the paper. Thus when picture signals representing dark areas are received, unit 75 thrusts pressure bar 73 upward pressing the paper and inked ribbon against the recording belt at the point where a stylus point 61p projects. The length of the dot or dash resulting from such engagement depends on the duration of the dark signal, the stylus point moving along in synchronism with the scanning slit at the transmitter, hence reproducing in extent and position the dark areas of the subject. Conversely when picture signals representing light areas are received the pressure bar 73 is drawn away from the stylus so that a corresponding light area is produced.

Referring now to Fig. 14, which shows diagrammatically in exaggerated manner the motion of armature 75a under various conditions, the normal or mid position of the armature is indicated at *a*. When current flows steadily in winding 75', the position of the armature is indicated at *a'*, and when current flows steadily in winding 75'' at *a''*. The point of particular interest is the motion of the armature upon reversal of the currents. Assume first that a "light" signal flows in winding 75'' holding the armature in position *a''* against the resilience of the centering means. Now upon striking a dark area, a "dark" signal is sent, and because of the fact that current must flow in one electronic relay in order to cut off the discharge of the other, there is a momentary increase or pulse of current in the middle conductor. These current conditions are graphically illustrated in Fig. 13 in which lines I to III represent the current-time relations of the currents through R1, R2, R3 respectively. At the instant of the overlapping current impulse, currents flow in both sections of winding 75, but since they are substantially equal and opposite, one nullifies the effect of the other. The magnetic pull on the armature is thus released, and normally, the resilient force would throw the armature to position *a'* on its first excursion. However, during the excursion interval, the current in winding 75'' suddenly drops to zero due to the de-ionization of T2. Hence the current in winding 75' becomes effective, exerting an accelating pull carrying the armature to position *a'''*. Assuming that the current in winding 75' continues on in steady state, the armature will return finally to position *a'*.

In practice, the armature does not travel as far as position *a'''* because pressure bar 73 strikes against a stylus point before that position is reached. And the above analysis of the motion of the armature is given for illustrative purposes only. It indicates the tendency of the motion of the armature, and that dot elements and the beginning of dash elements tend to be printed heavier than other elements, improving the sharpness of the reproduction. The practical advantage obtained is that the legibility of printed characters is materially improved.

Referring again the Fig. 13, it will be noted that a synchronizing signal, indicated by S in line I, is accompanied by two sharp current impulses S' and S'' in line III. The variations in current *i3* only are effective in auxiliary circuit 98 thus the grid of T3 receives two positive impulses for each synchronizing signal, namely at the beginning and end of the signal. These double impulses are advantageous not only in sharply marking the limits of the synchronizing signal, but also in the distribution of the local correction currents. Thus, for example, in case the receiver tends to lead, the first impulse will trip T3 while contacts 52' are closed, distributing a part current pulse to clutch magnet M2, while the second impulse will assure the tripping of T3 while contacts 53' are closed even if it should have deionized immediately upon the opening of contacts 52', thereby assuring the sending of a correction pulse to corrector manget M3. Were only a single tripping impulse at the beginning of the synchronizing signal provided, magnet M2 would receive a part pulse, but M3 would in some cases not receive an effective pulse until the departture from synchronism permitted T3 to trip while contacts 53' were closed. With the arrangements provided by the invention, corrective action is applied upon a

slight departure from synchronism, thus assuring close maintenance of synchronism.

Referring now to Fig. 6A which shows an adaptation of the transmitter shown in Fig. 6 to secure half-tone reproduction, photo-cell 26 is coupled to amplifier tube T in the same way as before except that a source of sustained alternating or pulsating electromotive force of suitable amplitude, indicated as an oscillator *f*, is connected in series with the source of steady bias potential for grid *g*, represented by battery B2. A varying potential due to the alternating potential of source *f* superimposed on the steady potential of source B2 is thus normally applied through resistor Rs to grid *g*.

Amplifier tube T is preferably coupled to the input circuits of tubes T1 and T2 in such a way that the potentials applied to grids *g1* and *g2* will be at all times proportional to the plate current flowing in tube T. A resistance network or potentiometer P1, P2 provides a suitable coupling means. The voltage across sections P1 and P2 will vary proportionally with the plate current in tube T, their ratio being variable according to the setting of wiper *w*. Tube T1 is conveniently provided with proper stabilizing bias by the voltage drop across resistor section P1 due to the plate current of T flowing therein. When photo-cell 26 is dark, the potential applied to *g1* is of such value as to permit T1 to ionize and when the photo-cell is light, the potential applied to *g2* is such that T2 ionizes. Tubes T1 and T2 are arranged for inverter action as described in connection with Fig. 6. Source F may be of any source of alternating or pulsating electro-motive force of suitable frequency and amplitude, but is preferably a relaxation oscillator producing a "saw-tooth" wave form. The frequency used may vary over a wide range and very satisfactory results have been secured in the range of about 1000 to 1500 cycles. These values are given as illustrative only, as the frequency can be greatly increased or reduced if desired.

The operation in transmitting half-tone picture signals is as follows: Referring to Fig. 15 in connection with the circuit of Fig. 6A, two conditions are represented the left hand portion of the diagram showing the conditions for the sending of block areas, and the right hand portion showing the conditions for sending intermediate or gray areas. Referring first to the left hand portion, the instantaneous potential applied to grid *g* is represented by *eg*. This potential is the resultant of steady negative bias potential Ec due to B2, variable potential *eo* (shown as a saw-tooth wave form) due to oscillator *f*, and potential E' due to the photo-cell current in resistor Rs. The voltage *e* represents that value of *eg* at and above which tube T2 will be tripped. Thus whenever the resultant steady or momentary voltage *eg* rises above the level *e*, tube T2 will be tripped and the recorder will reproduce a white area, and conversely when it falls below the level *e*, tube T1 will be tripped, causing the reproduction of a black area.

The operating potentials on T, T1, and T2 are so adjusted that when photo-cell 26 is dark, i. e. when a solid black area is being scanned, E, being very small or non-existent, the resultant voltage *eg* remains below the critical value *e*, and tube T2 remains un-ionized. Tube T1 is tripped with steady current flowing therethrough and the recorded will record black.

The right hand portion of the diagram represents the condition when an intermediate or gray area is being scanned. In this case photo-cell 26 receives an increased amount of light, potential E' being correspondingly increased. This has the effect of raising the resultant voltage *eg*. Thus at the times when the alternator voltage *eo* is aiding the potential E' derived from the photo-cell the resultant voltage *eg* is raised above the critical level *e*; when *eo* is of lesser value, or opposed to E', the resultant voltage falls below the critical level. Whenever the resultant voltage exceeds the critical level, tube T2 will be tripped and tube T1 cut off, thus causing a light area to be reproduced at the recorder. As the resultant potential falls below the critical value, tube T1 is tripped and tube T2 cut off, thus causing a dark area to be reproduced at the recorder. The recorder will thus reproduce a series of dashes with gaps therebetween as indicated in exaggerated proportions. The eye integrates areas so recorded into shades less dark than black, that is, the area so recorded appears dark gray. When more light strikes photo-cell 26 (as from a lighter shade of gray) the relationship of the dashes changes, becoming shorter and the gaps between the dashes becoming correspondingly longer, producing the effect in the reproduced copy of lighter shades.

Finally in scanning white areas, the resultant potential remains continuously above the critical value, tube T2 is continually ionized and thus white areas are reproduced at the recorder. It will be understood that the relative values of potential represented are illustrative only and are not in any way intended as limiting the practicing of the invention.

The frequency of the dot-dash combinations is controlled by the frequency of oscillator *f*, while the ratio of dot-dash lengths is controlled by photo-cell 26 in accordance with its response to the light values of the areas being scanned. Thus half-tone effects are produced in recording, reproducing the shades of the original.

The adjustment of the various factors to obtain the desired half-tone effects depends in part on the subject matter being transmitted, and in part on the characteristics of the transmission line. The principles to be followed in making such adjustments and in providing desired operating conditions are well known in the art and consequently do not require detailed discussion. The circuit changes and apparatus required to convert the system from full tone to half-tone are so simple that it will be readily apparent to those skilled in the art that the two types of recording can be combined, or made interchangeable, by the addition of suitable switching equipment.

It should be observed that since the system of the invention does not require carrier currents, and only the fundamental picture signal frequencies need be transmitted, the frequency requirements of the transmission line are less rigid than would otherwise be the case.

When the facsimile system of the invention is to be worked over long distance lines, or over radio circuits and when one transmitter must operate a plurality of receivers, it may be desirable for the transmitter merely to control the receiver rather than to actuate the magnetic recorder directly. The sending and receiving arrangements previously described can readily be adapted to such applications, such adaptation being facilitated by additional units of equipment next to be described.

Referring now to Fig. 16, which shows a con-

verter-amplifier unit forming part of the invention, the parts are identical in description and function with the parts identified by like characters in Fig. 6 and described in connection therewith.

Referring now to Fig. 17, which shows a converter-coupler unit according to the invention, this unit comprises a transformer Tr2 provided with a center-tapped balanced primary and simple secondary as shown, this type of transformer being commonly known as an audio line transformer, and suitable line regulating impedances. Variable impedances R11, R12 and R13 are preferably connected one in series with each input terminal, as shown. These impedances are useful in adjusting signal levels and in balancing the lines but are not strictly essential since suitable impedance values may be incorporated in the transformer windings or elsewhere in the circuit.

Referring now to Fig. 19 which shows in diagrammatic form a long distance transmission system for facsimile signals, this system is comprised of the apparatus shown in Figs. 6 (or 6a) and 17 constituting the transmitter, the apparatus shown in Figs. 16 and 12 constituting the receiver, and a transmission line therebetween. Referring first to Fig. 6, it is seen that the light variations falling on the photo-cell are converted into electrical variations, these variations are amplified by amplifier tube T and applied to the primary of transformer Tr1. The currents in the primary of Tr1 represent the light values reaching photo-cell 26; the voltage changes appearing at the secondary terminals of Tr mark the changes in the current of T. Electron relays T1 and T2 convert these changes into timed, alternative direct-current impulses. The coupler unit of Fig. 17 reconverts the alternative impulses into aperiodic line signals characterized by time and polarity which mark the limits of the intermediate impulses, and thus the changes in the photo-cell current.

Fig. 21 shows the relation between the currents in conductors I and II of Fig. 6, (which currents represent the alternative light and dark areas of the record) and the timed and polarized signals transmitted to the line by the converter-coupler unit of Fig. 17. The current in conductors I and II are alternative direct currents as illustrated in Fig. 13, a "dark" or synchronizing signal being represented by S. By reason of the action of the apparatus of Fig. 17, the beginning of a current pulse S is marked by a positive line signal S' and its end by a negative signal S'' (or vice versa if desired). These signals constitute the printing signals transmitted through the two-wire line indicated in Fig. 19. It should be noted that these signals indicate not only the times at which light values change, but also the direction in which the change occurs.

At the receiving station, the received signals are again converted into alternative direct-current impulses by the converter-amplifier unit of Fig. 16, which impulses are utilized by the recorder shown in Fig. 12 as described in connection therewith. Thus the light variations falling on the photo-cell are faithfully represented by the operating impulses at the receiver.

Assuming now that it were desirable to repeat the facsimile signals into another section of the transmission line, either for further propagation along the same long-distance circuit, or into a branch or fork circuit. A repeater-amplifier for such purposes is shown in Fig. 18 and comprises the apparatus shown in Figs. 16 and 17. This repeater reconstructs and amplifies the facsimile signals and passes them on to the next section line indicated by "Out". Several important advantages are obtained by the arrangement. For example, the signals are sharpened or regenerated. Since the repeater tubes can be tripped by very feeble signals, the amount of power taken out of the circuit by the repeater is negligible,—a most important consideration for branch-line and fork-line repeaters. Since all line signals are single impulses of substantially the same constant amplitude and duration, lines can be balanced to a single equivalent frequency. Because of this and other related factors, an efficient transmission line is less costly to provide than when a band of frequencies must be transmitted.

Fig. 20 is a schematic diagram of a radio facsimile system, the essential elements of the transmission system being clearly indicated. Since the operation of the radio elements are well understood, and the other elements of the system have already been described in detail herein, further description is not required.

Without further analysis, it should be apparent that I have provided a complete facsimile system of comparatively simple nature meeting in a highly satisfactory and practical manner the many exacting requirements of such systems.

While the methods and forms of apparatus herein described constitute preferred embodiments of the invention, it is to be understood that the invention is not limited to these precise methods and forms of apparatus, and that changes may be made therein without departing from the scope of the invention which is defined in the appended claims.

What is claimed is:

1. A facsimile system of the character described comprising means for scanning a subject to determine the light values of successive elemental areas thereof, means for transmitting a signal only upon a change in light values of the subject, means for receiving said signals, reproducing means, means for controlling the reproducing means for causing the continued reproduction of an area of predetermined light value in the absence of received signals, and means for controlling the reproducing means for effecting the reproduction of an area of light value contrasting with the former upon receipt of a signal.

2. A facsimile system of the character described which comprises means for scanning a subject to determine the light values of successive elemental areas thereof, means for transmitting a signal indicative of a light area, means for transmitting a signal indicative of a dark area, means for causing the alternate transmission of said signals indicative of an area of intermediate shade including means to initiate the signal impulses aperiodically, means for receiving said signals, reproducing means, means for controlling the reproducing means for causing the reproduction of a light area in response to said first mentioned signal, means for controlling the reproducing means for causing the reproduction of a dark area in response to said second mentioned signal, and means for controlling the reproducing means for causing the alternate reproduction of light and dark areas in response to said alternate signals to give a visual effect of an area of intermediate shade.

3. In a facsimile system, a transmitter includ-

ing a record sheet, means for scanning said record sheet to determine the light values thereof, signal transmitting means for alternately transmitting aperiodic signals in accordance with the light values of said record and periodic synchronizing signals, and means for causing the initiating of transmission of signals including means controlled by the sending of a synchronizing signal for controlling the said initiating means.

4. In a facsimile system, a transmitter including a record sheet, means for scanning said record sheet to determine the light values thereof, signal transmitting means for alternately transmitting aperiodic signals in accordance with the light values of said record and periodic synchronizing signals, and means controlled by the record sheet when in scanning position for causing the initiating of transmission of signals by the sending of a synchronizing signal.

5. In a facsimile system, a transmitter including a record sheet, means for scanning said record sheet to determine the light values thereof, signal transmitting means for alternately transmitting aperiodic signals in accordance with the light values of said record and periodic synchronizing signals, means controlled by the record sheet when in scanning position for causing the initiating of transmission of signals by the sending of a synchronizing signal, and means controlled by the record sheet for terminating the transmission of signals when the record sheet has progressed beyond a predetermined point.

6. In a facsimile transmitter, a record sheet, means for scanning said sheet, means controlled by said scanning means for transmitting signals, means controlled by said record sheet upon the beginning and ending of scanning relationship with said scanning means for initiating and terminating the generation of signals.

7. In a facsimile system, a transmitter, a recorder including an elongated record sheet, means for feeding the sheet during the transmission period, and means under the control of the transmitter for cutting the record sheet at the end of the transmission period.

8. A facsimile system having a transmitter, a receiver, a signalling channel therebetween, a scanning belt provided with a plurality of scanning slits at the transmitter, drive means therefor, a recording belt provided with a plurality of stylii at the receiver, drive means therefor, and means under the control of the transmitter for starting the recording belt and including means for thereafter maintaining synchronous operation between the recording belt and the scanning belt.

9. A facsimile system having a transmitter, a receiver, a signalling channel therebetween, scanning means at said transmitter including a plurality of scanning apertures and means for causing said apertures to scan successive lines of a record sheet, means for producing signals representing the record scanned by said apertures, means for producing periodic synchronizing signals, recording means at said receiver including a plurality of recording stylii, means for causing said stylii to record upon successive lines of a record steet, and means under the control of said synchronizing signals for starting the stylii and including means for thereafter maintaining a synchronous relation between said stylii and said scanning apertures.

10. In a facsimile system, a transmitter, a receiver, a signalling channel therebetween, scanning means at the transmitter including a moving member provided with a plurality of scanning apertures, means for transmitting periodic signals indicative of the position of said member, receiver means for receiving said signals, recording means at said receiver including a movable member carrying a plurality of recording stylii, and means for arresting said member with one of said stylii in a predetermined position, and means controlled in response to said periodic signals for placing said movable member in motion and including means for thereafter maintaining the movable member in synchronism with said moving member.

11. A facsimile system of the character described comprising means for scanning the subject to determine the light values of successive elemental areas thereof, means responsive to the scanning means comprising at least a pair of electron discharge devices including means for rendering said devices conductive alternately upon scanning dark and light areas to initiate aperiodically distinctive signals representative of the scanned areas, means whereby the said devices when rendered conductive are maintained conductive until an area differing in light value is scanned, and means for rendering the conductive device non-conductive and simultaneously therewith rendering the other device conductive.

12. A facsimile system of the character described comprising means for scanning the subject to determine the light values of successive elemental areas thereof, means responsive to the scanning means comprising a pair of electron discharge devices connected in push-pull arrangment including means for normally biasing them to be non-conductive, and means controlled by the scanning means to overcome the bias conditions for rendering them conductive alternately upon scanning light and dark areas respectively.

13. A facsimile system of the character described comprising means for scanning the subject to determine the light values of successive elemental areas thereof, means responsive to the scanning means comprising a pair of gas discharge devices of the trigger action type connected in push-pull arrangement, including means for normally biasing them to be non-conductive, means controlled by the scanning means to overcome the bias conditions for rendering them conductive alternately upon scanning light and dark areas, and means common to the output circuits of said devices for rendering the conductive device non-conductive whenever the other device is rendered conductive.

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