

June 7, 1949.

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2,472,774

IRREGULAR INTERLACE SCANNING SYSTEM

Filed Oct. 17, 1945

3 Sheets-Sheet 1

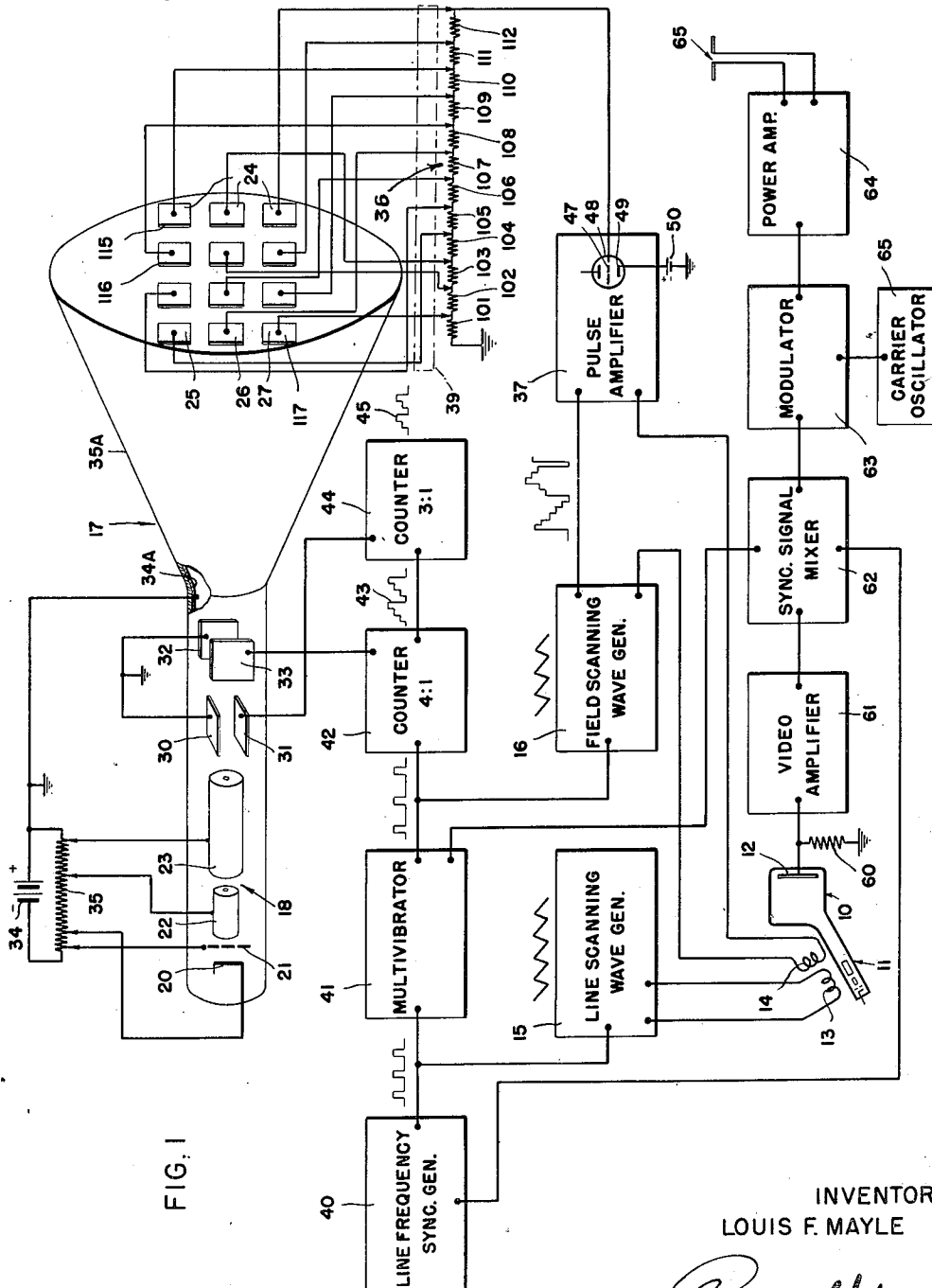


FIG. 1

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FIG. 3

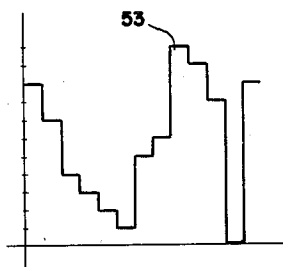


FIG. 2

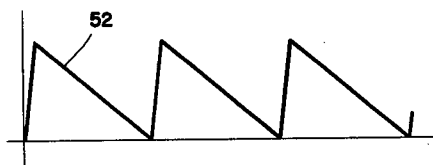


FIG. 5

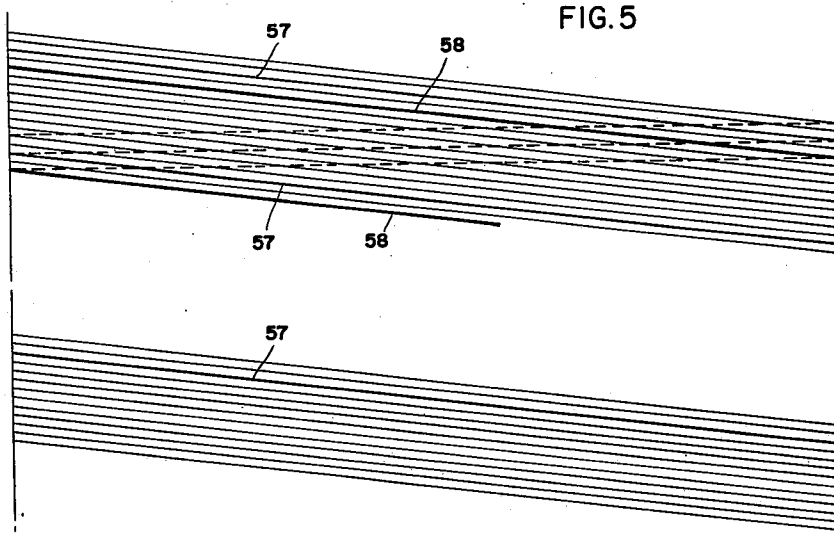
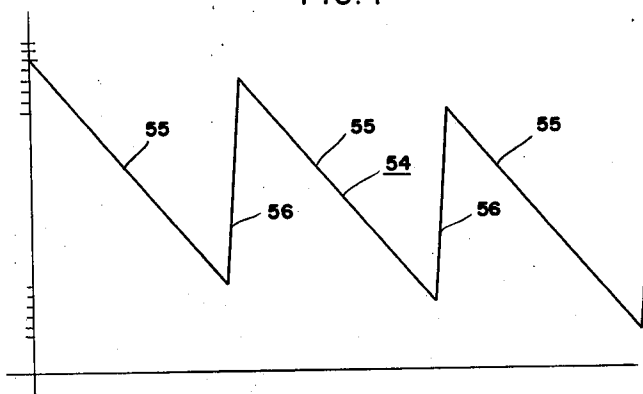


FIG. 4



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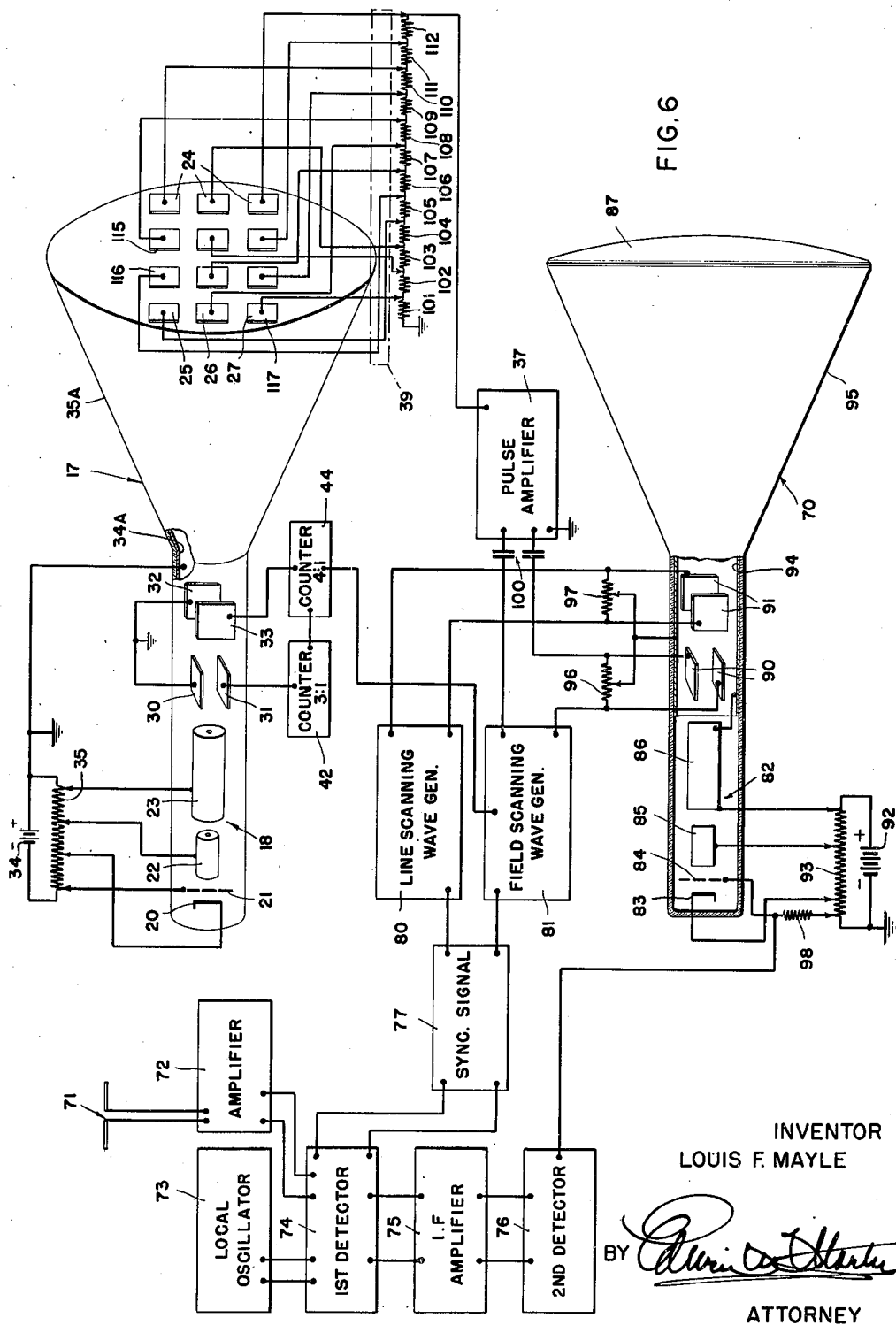
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UNITED STATES PATENT OFFICE

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IRREGULAR INTERLACE SCANNING SYSTEM

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6 Claims. (Cl. 178-7.7)

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This invention relates generally to a television system, and more particularly relates to a method of and apparatus for effecting secrecy in television systems.

It is conventional practice to scan the image of an object to be transmitted in interlaced fashion. Thus, each complete frame, representative of the optical image at a certain instant, comprises generally a group of fields of consecutively scanned parallel lines arranged so that the lines of one field fall between the lines of another field in each group. According to the standards adopted by the Radio Manufacturers Association, a frame comprises two fields. Two general methods have been devised for effecting interlaced scanning. According to one conventional interlaced scanning system, an odd number of lines is used for scanning each frame so that each field comprises a fractional number of lines. Hence, the line scanning frequency is not a multiple of the field scanning frequency. If a frame comprises two fields, for example, the number of lines per field is one-half plus an integer. Each field is scanned beginning at the top of the image area. However, the beginning of the scanning of successive fields is displaced by a fraction of a line along the top edge of the image area. The field scanning as well as the line scanning frequency repeats for each field scanning period. The retrace period of successive fields, however, begins after a different fractional amount of the last line has been scanned. Interlaced scanning systems of this type have been devised where each frame comprises two or more fields of consecutively scanned parallel lines.

In accordance with another interlaced scanning system, an even number of lines is used for each frame comprising two fields. Here the line scanning frequency is a multiple of the field scanning frequency. However, the return trace between successive fields of a group is of unequal duration and, hence, the first line of successive fields begins at different levels. The number of lines in each field is an integer. The vertical deflection of consecutive fields in each group is usually effected by means of rectangular pulses which are superimposed upon the conventional sawtooth wave of field scanning frequency.

It would be desirable to scan the image area at a rate of more than two fields per frame but as soon as the number of fields in a frame exceeds two, difficulty is experienced due to the phenomenon known as "crawling," that is the appearance of moving waves in the reproduced picture when the lines of the fields of each frame follow each other in consecutive order. It has been recognized in the art that it is desirable for this reason to scan a plurality of fields forming a frame in irregular sequence. This, however, can not be effected by means of the interlaced

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scanning system where an odd number of lines is used for scanning each frame. In that case the beginning of the scanning of successive fields is displaced by a fraction of a line and hence the fields follow each other in regular sequence. However, a television system has been suggested where each frame comprises four fields. The first pair of fields is displaced with respect to the succeeding pair of fields in the manner of an even line interlaced scanning system. On the other hand, each pair of fields is scanned in accordance with the odd line interlaced scanning system so that every field comprises a fractional number of lines.

For secrecy purposes it would also be desirable to scan the image to be transmitted in such a manner that each frame comprises a large number of fields which are scanned, transmitted and reassembled in predetermined irregular sequence. A system of this type has obvious advantages for retaining secrecy of the transmitted television intelligence and may find application for news services and the like where subscribers may receive television pictures transmitted by a central station. By using a prearranged code, the television pictures can only be received by those who have knowledge of the code.

It is the principal object of the invention, therefore, to provide a television secrecy system.

A further object of the invention is to provide apparatus for effecting interlaced scanning for television systems so that a group of fields of parallel lines equivalent to a frame is scanned, transmitted and received one after the other in predetermined irregular sequence.

Another object of the invention is to provide apparatus for displacing each field in a group of fields of parallel consecutively scanned lines in irregular predetermined sequence and changing at will the sequence of the displacements of successive fields in any one group.

In accordance with the present invention, there is provided a scanning circuit for determining the order of interlace of successive scanning fields of a television tube comprising first electron deflecting means for defining the horizontal component of a scanning trace. Second electron deflecting means are provided which include a source of waves for defining the vertical component of the scanning trace. Means are further provided for generating pulses of irregular amplitude to provide irregular order of interlace, and, finally, means for superimposing the pulses on the waves.

For a better understanding of the invention, together with other and further objects thereof, reference is made to the following description, taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the accompanying drawings:

Fig. 1 is a schematic circuit diagram, mostly in block form, of a television transmitting system and associated electronic commutator embodying the present invention;

Figs. 2, 3 and 4 are curves representing electric waves developed at various parts of the transmitting system of Fig. 1;

Fig. 5 illustrates diagrammatically the path traveled by the scanning beam over the target of the transmitting system of Fig. 1; and

Fig. 6 is a schematic circuit diagram, mostly in block form, of a television receiving system and associated electronic commutator in accordance with the invention.

Referring now more particularly to Fig. 1 of the drawings, there is illustrated a television transmitting system including picture signal generating tube 10, which may either be of the storage type, as shown, or an image dissector tube. Signal generating tube 10 comprises electron gun 11, shown schematically, mosaic electrode 12 and line scanning elements 13 and field scanning elements 14, which may consist of pairs of scanning coils. For developing scanning currents in accordance with the present invention, there are provided sawtooth line scanning wave generator 15 and sawtooth field scanning wave generator 16 connected, respectively, to scanning coils 13 and 14. In accordance with the present invention, there is further provided electronic commutator 17 for developing groups of rectangular pulses of predetermined amplitudes. Electronic commutator or cathode ray tube 17 includes electron gun 18 comprising cathode 20, control grid 21, first anode 22 and second anode 23. Electron gun 18 is arranged for developing an electron beam and directing it towards a group of twelve targets 24 arranged in three rows 25, 26 and 27, each row comprising four targets. Targets 24 are electrically insulated from each other and made of conductive material, such as metal. Pairs of deflecting plates 30, 31 and 32, 33 are provided for periodically deflecting the electron beam across targets 24.

Operating potentials are supplied for the various elements of cathode ray tube 17 from a suitable source illustrated as battery 34 connected across potentiometer 35 and having its positive pole grounded. By means of suitable taps connected to potentiometer 35, control grid 21 is maintained at a potential that is a few volts negative against that of cathode 20, while anodes 22 and 23 are supplied with increasingly positive potentials with respect to cathode 20. Second anode 23 is connected to ground. Deflecting plates 30 and 32 are also connected to ground as illustrated. Electrode 34A, which may consist of a conductive coating on the inner surface of envelope 35A of tube 17, is also grounded.

A group of resistors, equal in number to the number of targets 24 in cathode ray tube 17, is indicated at 36 and connected in series between ground and pulse amplifier 37. Each target 24 has been shown connected between a selected number of resistors 36, indicated individually at 101 to 112, and ground to develop groups of rectangular pulses of predetermined different amplitudes. As will be explained in detail hereinafter, the number of targets 24 determines the number of pulses in a group, which in turn determines the number of fields in each frame of the interlaced scanning pattern. For the purpose of changing at will the connections between targets 24 and resistors 36 there may be provided

selector switches indicated schematically by box 39.

Let us assume that the number of lines per field is N , that the number of lines per frame is M , while the number of fields per frame is n and the frame frequency, that is the number of frames per second is f_{frame} . Then the line frequency $f_{\text{line}} = nNf_{\text{frame}}$, while the field frequency

$$f_{\text{field}} = nf_{\text{frame}}$$

In the present case M , the number of lines per frame, must be divisible by n , the number of fields per frame, in order to obtain an even line interlaced scanning pattern. Thus, M/n is an integer which equals N , the number of lines per field.

We may now assume that n , the number of fields per frame, is twelve corresponding to the twelve targets 24 of cathode ray tube 17. We may further assume a frame frequency f_{frame} of 30 per second. If we assume that M , the number of lines per frame is 600, then N the number of lines per field equals

$$\frac{M}{n} = \frac{600}{12} = 50$$

The line frequency

$$f_{\text{line}} = nNf_{\text{frame}} = 12 \times 50 \times 30 = 18,000$$

The field frequency $f_{\text{field}} = nf_{\text{frame}} = 12 \times 30 = 360$.

Referring again to Fig. 1 of the drawings, there is provided line frequency synchronizing signal generator 40 for developing synchronizing signals of rectangular wave shape at the line frequency, that is at 18,000 cycles per second. Synchronizing signal generator 40 is connected to line scanning wave generator 15 for synchronizing it at the line scanning frequency. Multivibrator 41, connected to line frequency synchronizing signal generator 40, reduces the line frequency by the factor N , the number of lines per field. Hence, multivibrator 41 develops rectangular pulses at a frequency of 18,000/50 or 360 cycles per second, which is equivalent to the field frequency. Multivibrator 41 is connected to field scanning wave generator 16 for synchronizing it at the field scanning frequency. Counter 42 is connected to multivibrator 41 and develops groups of pulses at one-fourth the frequency of that of the rectangular pulses developed by multivibrator 41, that is at a frequency of 90 cycles per second. The pulses developed by counter 42 are of rectangular stepped wave shape, as indicated at 43. Counter 44 is connected to counter 42 and develops groups of pulses of stepped rectangular wave shape, illustrated at 45, each group having a frequency equal to one-third that of one group of pulses 43 or 30 cycles per second.

Counter 42 is connected to deflecting plate 33, while counter 44 is connected to deflecting plate 31. Hence, the electron beam developed by electron gun 18 is deflected horizontally across each row 25, 26 and 27 of targets 24 by means of the electric field developed by deflecting plates 32, 33 connected to counter 42. The wave shape of deflecting pulses 43 is such that the electron beam impacts each target 24 for a predetermined duration which is substantially equal to the field scanning period. The electron beam traverses one row of targets 24 at a frequency which is three times the frame frequency or 90 cycles per second. Deflecting plates 30 and 31 connected to counter 44 develop an electric field which deflects the electron beam vertically across targets 24, that is from row 25 to 26 and then to 27. The wave shape of deflecting pulses 45 is such that all three rows 25 to 27 are scanned once during the

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frame scanning period and, accordingly, all twelve targets 24 are scanned once in this interval. The deflecting pulses developed by counters 42 and 44 are locked in with the line scanning frequency and field scanning frequency by means of their inter-connection with multivibrator 41 and synchronizing signal generator 40.

When the electron beam developed by electron gun 18 impacts one of the targets 24, current source 34 is effectively connected to that target through a resistance represented by the resistance of the electron beam. In accordance with the present invention, each target 24 is connected between a selected number of resistors 36 and ground as illustrated. Thus, by way of example target 115, being the first target in row 25, has been shown connected between resistors 101 to 110, inclusive, that is between ten resistors and ground. When the electron beam impacts target 115, a current flows from ground through resistors 101 to 110, inclusive, target 115 and through the electron beam back to battery 34. Target 116, which is the next target in row 25 has been shown connected between resistors 101 to 108, inclusive, that is between eight resistors and ground. Accordingly, when the electron beam impacts target 115, a negative voltage drop is developed across resistors 101 to 110 which is impressed upon grid 47 of electron tube 48. Cathode 49 of tube 48 is connected to ground through battery 50 positively biasing cathode 49 which is equivalent to a negative bias of grid 47. The negative pulses developed across resistors 36 are thus amplified by tube 48 forming part of pulse amplifier 37. Amplifier 37 may either be a direct current amplifier or an alternating current amplifier well compensated for low frequencies and arranged to pass the rectangular pulses developed across resistors 36.

It will now be evident that the amplitude of the pulses developed across resistors 36 will depend upon which one of targets 24 is impacted by the electron beam. Since the current of the electron beam is constant, the voltage drop between ground and resistors 36 depends upon the number of resistors which are connected between the electron beam and ground. Accordingly, when the electron beam impacts target 115 there are ten resistors 101 to 110 connected between the beam and ground. The negative voltage drop developed across resistors 101 to 110 is, therefore, ten times as large as the voltage drop developed when the beam impacts target 117 connected between resistors 101 and ground. In view of the fact that there are twelve targets 24 and twelve resistors 101 to 112, groups of pulses are developed, each group consisting of twelve pulses having different amplitudes. The sequence of the twelve pulses in each group, that is the sequence of the amplitudes of the pulses, may be changed by changing the connections between targets 24 and resistors 36.

As will be explained hereinafter, the sequence in which the fields in any frame are scanned depends upon the amplitudes of the pulses developed by electronic commutator 17. Accordingly, there is an almost unlimited number of combinations in which the twelve fields may be scanned and transmitted.

Referring now to Fig. 2, there is illustrated sawtooth current wave 52 which is developed by field scanning wave generator 16 at the field frequency, that is at 360 cycles per second. The groups of rectangular pulses developed by electronic commutator 17 and amplified by pulse am-

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plifier 37 are superimposed upon sawtooth current wave 52. This is effected by arranging pulse amplifier 37 in one of the leads connecting field scanning wave generator 16 to scanning coils 14.

The output wave developed by pulse amplifier 37 is illustrated on enlarged scale in Fig. 3. Fig. 3 shows one group of rectangular pulses 53. The duration of each pulse corresponds to the field scanning period. Each group of pulses 53 comprises twelve rectangular pulses of different amplitudes, as clearly shown in Fig. 3. Thus, the duration of one group of pulses 53 equals the frame scanning period which corresponds to 30 cycles per second.

It should be understood that the amplitude of sawtooth current wave 52 is much larger than that of rectangular pulses 53. Each sawtooth current wave 52 deflects the electron beam in signal generating tube 10 across substantially the entire height of mosaic electrode 12, while each of the rectangular pulses 53 deflects the electron beam over a few of the 600 lines of a picture frame.

The composite current wave impressed upon deflecting coils 14 is illustrated schematically in Fig. 4. Sawtooth current wave 54 of Fig. 4 is obtained by superimposing sawtooth current wave 52 upon rectangular pulses 53. As stated above, the duration of each rectangular pulse 53 equals that of one cycle of sawtooth current wave 52. The trace portions 55 of sawtooth wave 54 are equal in length. However, the retrace portions 56 differ in length in accordance with the superimposed rectangular pulses 53.

The interlaced scanning pattern of the electron beam effected by the electric field developed by sawtooth wave 54 in scanning coils 14, and the line scanning sawtooth current wave developed by generator 15 is illustrated in Fig. 5. The scanning of each of the twelve fields of which a frame consists begins at the left hand edge of the picture area. Each field comprises fifty parallel lines which are scanned so that every twelfth of the 600 lines of the picture area is scanned during one field scanning period. The beginning of the scanning of each field is determined by rectangular pulses 53. Thus, the first field in a group of fields begins with the third line 57, as indicated in Fig. 5. Then, in accordance with the pattern of rectangular pulses 53, the second field begins with the fifth line 58, as indicated in Fig. 5. The fields follow each other in predetermined irregular sequence until the entire picture area has been scanned within one frame scanning period equivalent to twelve field scanning periods or at a frequency of 30 cycles per second. As pointed out hereinabove, the sequence in which the fields are scanned may be changed at will by changing the connections between targets 24 of electronic commutator 17 and resistors 36. The fields are transmitted and received according to a predetermined code.

Thus, mosaic electrode 12 is scanned by the electron beam developed by electron gun 11 in accordance with a predetermined interlaced scanning pattern. When mosaic electrode 12 is scanned, picture signals are developed across grounded resistor 60 connected to the signal plate of mosaic electrode 12. The thus obtained voltage variations are amplified in video amplifier 61. Connected in cascade to video amplifier 61 are synchronizing signal mixer 62, modulator 63, power amplifier 64 and dipole antenna 65. Synchronizing signal mixer 62 is connected to line synchronizing signal generator 40 and multivibrator 41 to mix the horizontal and vertical syn-

chronizing signals with the amplified video signals obtained from video amplifier 61. Carrier oscillator 65 connected to modulator 63 develops a carrier wave which is modulated with the composite television signal obtained from mixer 62 in modulator stage 63. The modulated carrier wave is then amplified by power amplifier 64 and radiated into space by dipole antenna 65.

Referring now to Fig. 6 in which like components are designated by the same reference numerals as were used in Fig. 1, there is illustrated a television receiving system including picture signal reproducing tube 70. The modulated carrier signal radiated by dipole antenna 65 is received by dipole antenna 71 and amplified by radio frequency amplifier 72. The amplified carrier wave obtained in the output circuit of amplifier 72 is mixed with another carrier wave developed by local oscillator 73 and demodulated by first detector stage 74 to obtain an intermediate frequency signal. Connected in cascade to first detector 74 are intermediate frequency amplifier 75 arranged for amplifying the intermediate frequency signal and second detector 76 for developing the demodulated video signal. Synchronizing signal separator 77, connected to first detector 74, is arranged for separating the horizontal and vertical synchronizing signals. Line scanning wave generator 80 and field scanning wave generator 81 are connected to synchronizing signal separator 77 for synchronizing the frequencies of the waves developed by generators 80 and 81 with the synchronizing signals developed by separator 77.

Picture signal reproducing tube 70 includes electron gun 82 comprising cathode 83, control grid 84, first anode 85 and second anode 86. The electron beam developed by electron gun 82 is focused upon luminescent screen 87 of reproducing tube 70. The electron beam is deflected by deflecting plates 90, 90 and 91, 91. Operating potentials are supplied for the various elements of signal reproducing tube 70 from a suitable source illustrated as battery 92 connected across potentiometer 93 and having its negative pole grounded. Control grid 84 is kept at a potential that is a few volts negative against that of cathode 83 by a suitable tap connected to potentiometer 93. First anode 85 and second anode 86 are maintained at increasingly positive potentials with respect to cathode 83 by suitable taps connected to potentiometer 93. Electrode 94 which may be arranged as a conductive coating on the inner surface of envelope 95 is connected to second anode 86.

Deflecting plates 91, 91 are connected to line scanning wave generator 80 while deflecting plates 90, 90 are connected to field scanning wave generator 81 through pulse amplifier 37. The leads of deflecting plates 90 and 91 are connected through resistors 96 and 97, respectively, each having a center tap connected to electrode 94. Thus, the average potential of deflecting plates 90 and 91 equals that of second anode 86 and electrode 94.

The receiver system just described, with the exception of pulse amplifier 37, operates in a conventional manner. The video signal obtained from the output circuit of second detector 76 is impressed across resistor 98 arranged between control grid 84 and ground. Hence, the intensity of the electron beam developed by electron gun 82 is controlled by control grid 84 in accordance with the received picture signals. The electron beam is deflected across luminescent screen 87

in two directions normal to each other in accordance with the line scanning and field scanning frequencies. The electron deflecting waves developed by generators 80 and 81 correspond in frequency and phase to those developed by generators 15 and 16 of the transmitting system. The frequencies of the waves developed by generators 80 and 81 are synchronized with those of the transmitting station by means of horizontal and vertical synchronizing signals developed by synchronizing signal separator 77, as is conventional.

In accordance with the present invention, there is provided electronic commutator 17 at the receiving station which may be identical to commutator 17 of Fig. 1. In the same manner as explained in connection with Fig. 1, rectangular pulses are developed across resistors 36 which are amplified by pulse amplifier 37. Pulse amplifier 37 may be a direct current amplifier or an alternating current amplifier well compensated for low frequencies. In accordance with the invention, the connections between targets 24 and resistors 36 are the same as those of electronic commutator 17 of Fig. 1. Thus, target 115 has been shown connected between resistors 101 to 110 and ground. Counters 44 and 42, which develop the electric fields for deflecting the electron beam of tube 17, are connected in cascade to field scanning wave generator 81 through which they are synchronized.

Hence, the electric pulses developed by pulse amplifier 37 are the same as pulses 53, illustrated in Fig. 3. Pulses 53 are superimposed upon the sawtooth voltage wave developed by field scanning wave generator 81 by connecting amplifier 37 between one deflecting plate 90 and generator 81. Preferably, condensers 100 are arranged between amplifier 37 and the leads connecting it to one plate 90 and to generator 81. Condensers 100 should have a capacitance large enough to pass pulses 53. They are provided for separating amplifier 37 which is at a direct current ground potential from deflecting plates 91 which have a high positive average potential against ground.

The electron beam developed by electron gun 82 is deflected in accordance with the same interlaced scanning pattern as is the electron beam developed by electron gun 11 of signal generating tube 10. Thus, the twelve fields of which each frame consists are scanned, transmitted and received in predetermined irregular sequence.

It is to be understood that each frame may consist of more or less fields than twelve, the number twelve being chosen for purposes of illustration. It is also to be understood that targets 24 of electronic commutator 17 may be arranged in any other suitable manner. However, by arranging targets 24 in a plurality of rows such as 25, 26 and 27, it is particularly simple to derive the waves for deflecting the electron beam of tube 17 from the field scanning frequency.

While there has been described what is at present considered the preferred embodiment of the invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A scanning circuit for determining the order of interlace of successive scanning fields of a television tube comprising first electron deflecting

means for defining the horizontal component of a scanning trace, second electron deflecting means including a source of waves for defining the vertical component of said scanning trace, means for generating pulses equal in duration to that of one of said waves and of irregular amplitude to provide irregular order of interlace comprising a commutating device, a plurality of conductive targets in said device, and means connected to said source of waves for driving said device in synchronism with said waves, potential divider means including sections connected between different ones of said targets for providing different potentials of irregular amplitude, and means for superimposing said potentials on said waves.

2. A scanning circuit for determining the order of interlace of successive scanning fields of a television tube comprising first electron deflecting means for defining the horizontal component of a scanning trace, second electron deflecting means including a source of sawtooth waves for defining the vertical component of said scanning trace, means for generating pulses equal in duration to that of one of said sawtooth waves and of irregular amplitude to provide irregular order of interlace comprising a commutating device, a plurality of conductive electrodes in said device, and means coupled to said source of sawtooth waves for driving said device in synchronism with said waves, potential divider means including sections coupled between different ones of said electrodes for providing different potentials of irregular amplitude, and means for superimposing said potentials on said sawtooth waves.

3. A scanning circuit for determining the order of interlace of successive scanning fields of a television tube comprising first electron deflecting means for defining the horizontal component of a scanning trace, second electron deflecting means including a source of waves for defining the vertical component of said scanning trace, means for generating pulses of irregular amplitude to provide irregular order of interlace comprising a cathode ray tube for generating a cathode beam, a plurality of electrodes in said tube arranged to be scanned successively by said cathode beam, and deflecting means coupled to said source of waves for deflecting said beam into impingement with said electrodes in predetermined sequence, potential divider means including impedances coupled between different ones of said electrodes for providing different potentials of irregular amplitude incident to impact of electrons on said electrodes, and means for superimposing said potentials on said waves.

4. A scanning circuit for determining the order of interlace of successive scanning fields of a television tube comprising first electron deflecting means for defining the horizontal component of a scanning trace, second electron deflecting means including a source of waves for defining the vertical component of said scanning trace, means for generating pulses of irregular amplitude to provide irregular order of interlace comprising a cathode ray tube for generating a cathode beam, a plurality of electrodes in said tube arranged to be scanned successively by said cathode beam, and deflecting means coupled to said source of waves for deflecting said beam into impingement with one of said electrodes after another at the same periodicity as said waves, po-

tential divider means including sections coupled between different ones of said electrodes for providing different potentials of irregular amplitude incident to impact of electrons on said electrodes, and means for superimposing said potentials on said waves.

5. A scanning circuit for determining the order of interlace of successive scanning fields of a television tube comprising first electron deflecting means for defining the horizontal component of a scanning trace, second electron deflecting means including a source of waves for defining the vertical component of said scanning trace, pulse generating means for generating pulses equal in duration to that of one of said waves and of irregular amplitude to provide irregular order of interlace comprising a cathode ray tube for generating a cathode beam, a plurality of electrodes in said tube arranged to be scanned successively by said cathode beam, and deflecting means connected to said source of waves for deflecting said beam into impingement with one of said electrodes after another at the same periodicity as said waves, potential divider means including sections connected between different ones of said electrodes for providing different potentials of irregular amplitude incident to impact of electrons on said electrodes, and means for superimposing said potentials on said waves.

6. A scanning circuit for determining the order of interlace of successive scanning fields of a television tube comprising first electron deflecting means for defining the horizontal component of a scanning trace, second electron deflecting means including a source of sawtooth waves for defining the vertical component of said scanning trace, pulse generating means for generating pulses equal in duration to that of one of said sawtooth waves and of irregular amplitude to provide irregular order of interlace comprising a cathode ray tube for generating a cathode beam, a plurality of electrodes in said tube arranged to be scanned successively by said cathode beam, and deflecting means connected to said source of sawtooth waves for deflecting said beam into impingement with one of said electrodes after another at the same periodicity as said waves, potential divider means including sections connected between different ones of said electrodes for providing different potentials of irregular amplitude incident to impact of electrons on said electrodes, and means for superimposing said potentials on said sawtooth waves.

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