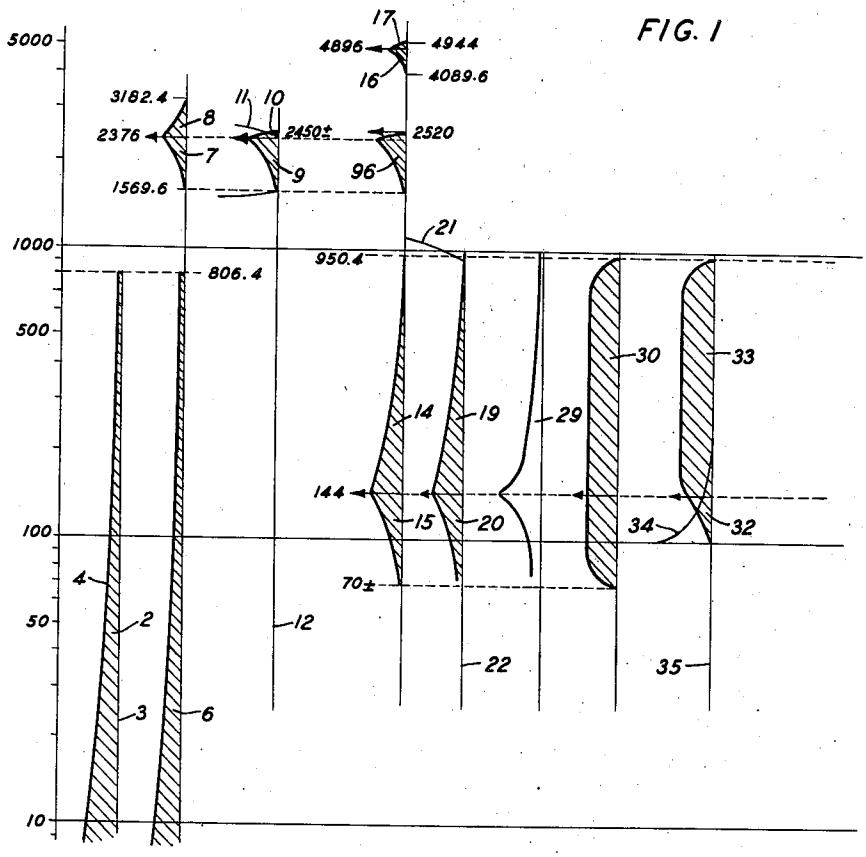
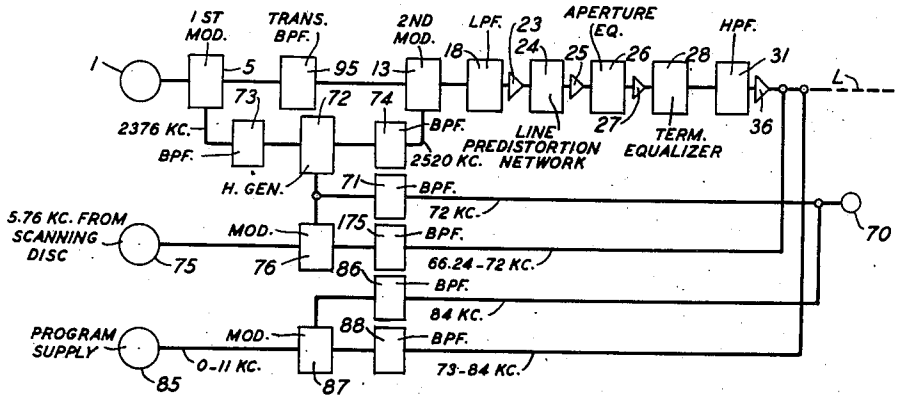
Aug. 25, 1942. C. L. WEIS, JR 2,293,870

ELECTRO OPTICAL IMAGE PRODUCTION

Filed Feb. 3, 1940 3 Sheets-Sheet 1

FIG. 1





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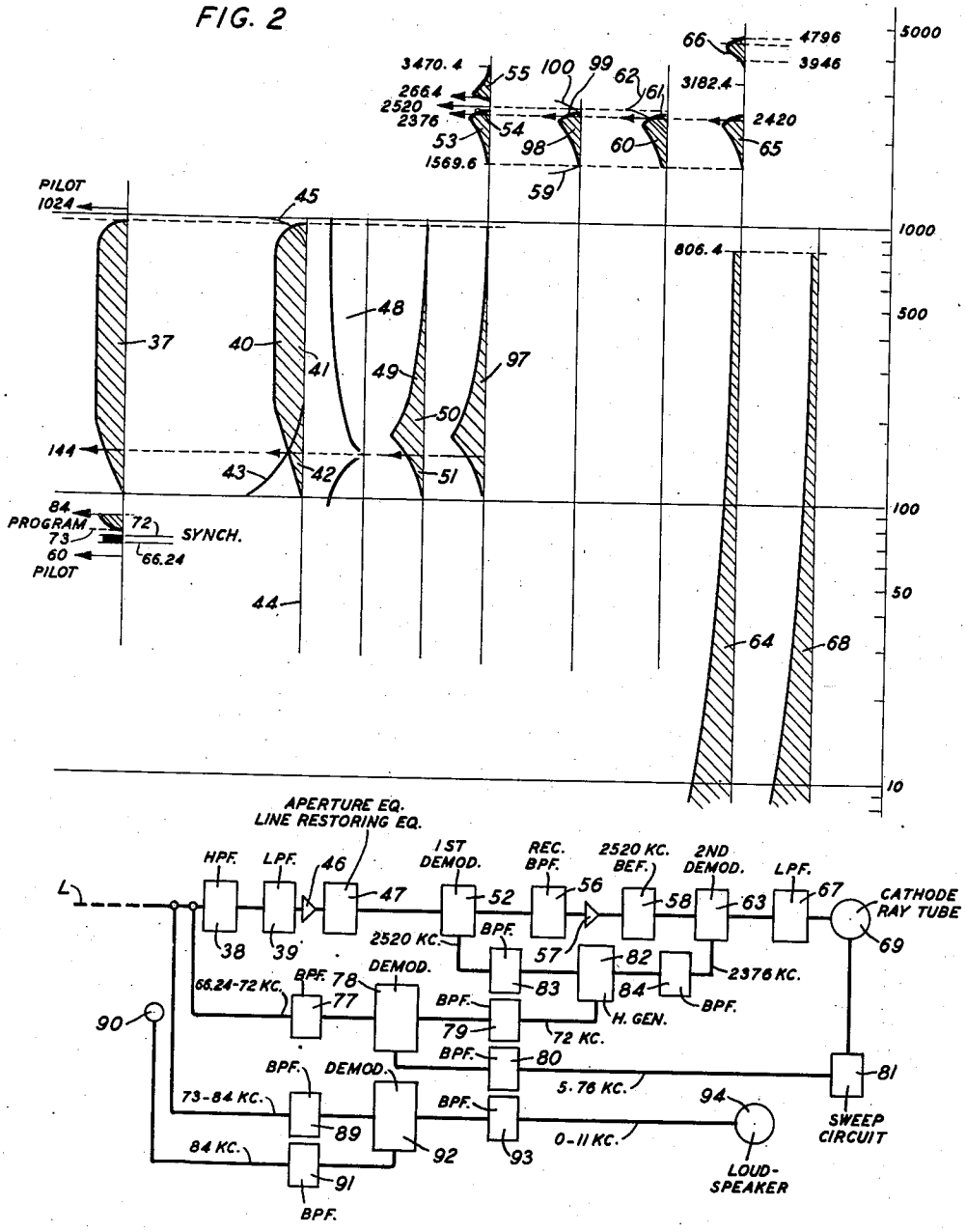
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ELECTRO OPTICAL IMAGE PRODUCTION

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FIG. 2



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FIG. 3

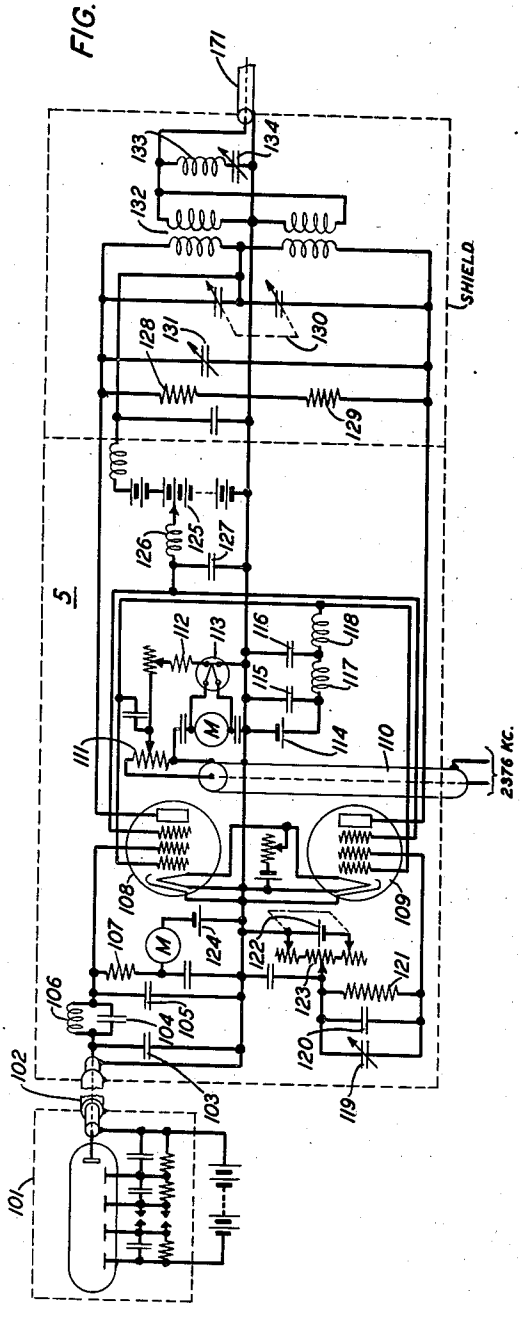
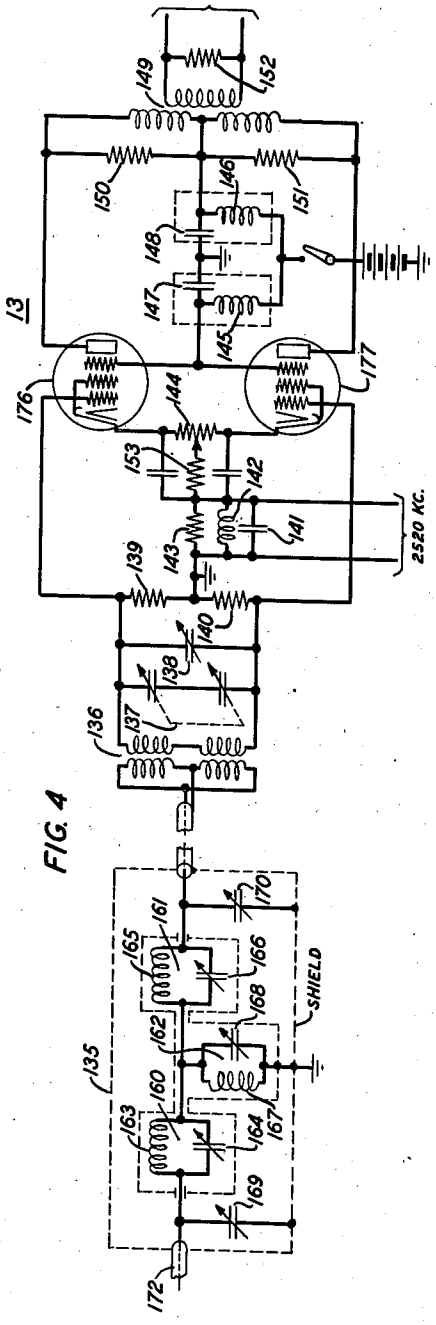


FIG. 4



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Patented Aug. 25, 1942

2,293,870

UNITED STATES PATENT OFFICE

2,293,870

ELECTRO-OPTICAL IMAGE PRODUCTION

Charles L. Weis, Jr., Mount Vernon, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application February 3, 1940, Serial No. 317,104

2 Claims. (Cl. 178—5.6)

This invention relates to electric signaling and more particularly to electro-optical image production.

An object of the invention is to provide a novel method of, and means for, accomplishing single side-band transmission in which use is made of the principle of vestigial side-band operation.

Another object is to provide for effective single side-band transmission of wide frequency band signaling currents over a cable of the coaxial type.

A further object is the effective selection of frequencies for effecting the transmission of a wide frequency signal band on a carrier basis, said transmission being within a range overlapping said signal frequency band.

Other objects and features of the invention will be apparent as the description of the invention proceeds.

The invention, in its various aspects, may be understood from the following brief description of an embodiment of it herein chosen for purposes of illustration and later described in detail. In this particular embodiment a coaxial cable is employed as the transmisison medium for simultaneously transmitting television, speech and television synchronizing current. The particular range of frequencies employed for each transmission and their spacing in the frequency spectrum were chosen, as explained below. Let it be assumed that the coaxial cable is designed to transmit television current of frequencies in the range between about 100 kilocycles and about 1000 kilocycles without undue distortion and cuts off in the region of 60 kilocycles. While a cable may be designed to satisfactorily transmit lower television frequencies, the difficulties encountered are such as to increase the cost. The cable when designed to transmit television frequencies satisfactorily only above 100 kilocycles, introduces phase shifts at lower frequencies of such magnitude as to unduly distort the television image. It is also found that in the region immediately below that where phase shifts for television become prohibitive, telephone transmission may be effected with tolerable distortion and that although the synchronizing frequency must be transmitted with a certain amount of fidelity the requirements are not so stringent as to preclude the synchronizing frequency or frequencies being transmitted in the region below 100 kilocycles. Therefore, sound signals are transmitted in the region immediately below 100 kilocycles and the synchronizing frequencies just below the range assigned to sound frequencies. For the transmission of television on the basis of 24 frames per second and a resolution of 240 lines, which is here chosen by way of example, the frequency band resulting from the scanning operation extends from zero to about 806 kilocycles. The problem therefore is to transform this wide frequency television band into a band which may be transmitted over the cable in the range between 100 kilocycles and 1000 kilocycles. In accordance with the invention this is accomplished by first modulating the wide frequency band upon a carrier current of such frequency that a considerable space in the frequency spectrum is left between the upper limit of the original modulating frequency band, which will appear as a modulation product, and the lowermost frequencies of the lower side-band resulting from the modulation. In selecting the frequency of the carrier higher order modulation components have to be taken into account. The next step in the process is that of lowering or shifting the modulated carrier frequency to the desired range for transmission, that is, a range from 100 kilocycles to 1000 kilocycles. This is accomplished by selecting a single side-band and modulating it upon a suitable carrier. In the utilization of a single side-band it was desired to employ the so-called principle of vestigial side-band operation according to which one side-band is selected along with a vestige of the other side-band in the immediate vicinity of the carrier frequency and the selected side-band is so shaped in the region adjacent the carrier frequency corresponding in width to the vestigial side-band that at the receiver the vestigial side-band components may be made to combine with the complemental frequencies derived from the transmitted side-band in such a manner as to give the equivalent effect of transmission on a single side-band having no amplitude distortion in the region of the carrier. This principle of providing a vestigial side-band to enable single side-band transmission is disclosed in the patent to H. Nyquist 1,748,186, patented February 25, 1930. The problem here under consideration, however, greatly complicates the application of the principle of vestigial side-band transmission in that in the application of that principle great care must be used to design a filter the output of which has in it the complemental frequencies in proper phase as well as amplitude, and proper phase control at the frequencies here involved is most difficult. After selection of the wanted side-band and the vestigial other side-band the

resulting current is applied to a second modulator along with a second carrier frequency of such value as to step the selected frequencies into the cable transmission range. In accordance with the invention there is employed a filter for the selection of the wanted side-band and a vestige of the unwanted side-band which does not produce the amplitude and phase characteristics of the complemental frequencies of the two side-bands in a manner to make use of the operation disclosed in the Nyquist patent, thus avoiding the complication of having to design a filter or correcting network to obtain these proper amplitude and phase relations at the high frequencies which the filter must pass. The process of obtaining the correct amplitude and phase relation of the complemental frequencies is deferred until the band is stepped to a lower range in which adequate phase relationships as well as proper amplitude discrimination may be obtained. It will be seen, however, that the band-pass filter after the first modulator in part accomplishes one step involved in the use of the vestigial side-band, namely, the selection of the necessary frequencies to be used in the application of the vestigial principle. Since it is impossible to design a filter which will cut off sharply it was necessary to place the cut-off where it would select the vestigial in a manner to change the amplitude of its components or at a higher point where it would leave these components intact and cut off the remaining portion of the upper side-band leaving a further undesired vestige. In accordance with the invention the latter course is adopted, the filter being designed to cut off in such manner, taking into consideration the position of the second carrier frequency, that none of the modulation components of the second modulator resulting from the unwanted vestigial will appear in the television transmission band range of 100 kilocycles to 1000 kilocycles. A band filter constructed to perform this filtering operation introduces undesirable phase shifts which can, however, be corrected, along with subsequent phase shifts, after the second step of modulation, in order to obtain the proper phase relations for application of the vestigial side-band principle. In the illustration given a frequency of 2520 kilocycles was chosen for the second carrier so that the selected lower side-band appeared in the output of the second modulator as side-bands of the second carrier, the lowermost of which extended from about 70 kilocycles to 950 kilocycles, the position of the original carrier in the lower side-band at 144 kilocycles and the extremity of the wanted vestigial farthest remote from the carrier, at about 100 kilocycles. The corresponding upper side-band extended from about 4089 kilocycles to 4944 kilocycles. By means of a low-pass filter the lower side-band was then selected.

One requirement not yet mentioned was taken into account in the selection of the first and second carrier frequencies. In accordance with the invention it was desired to transmit the speech in a range just below that suitable for television and the synchronizing frequencies in a range just below that suitable for speech. To accomplish this the program and synchronizing frequencies were modulated upon carirers of suitable frequency to place these transmissions in the desired ranges respectively. The speech carrier frequency was chosen at 84 kilocycles. After modulation the lower side-band extending to about 73 kilocycles was selected for transmission. A frequency for the synchronizing carrier was then selected such that it would fall below and close to the speech band and still be suitable to serve as a base frequency for generating harmonic frequencies for the first and second television carriers. Taking into consideration all the requirements above stated it was found that these requirements could be met by selecting the synchronizing carrier at 72 kilocycles, impressing this frequency upon a harmonic generator to generate odd harmonics, and selecting the thirty-third harmonic for the first television carrier and the thirty-fifth harmonic for the second television carrier. This put the first television carrier at 2376 kilocycles, in a position where proper selection between the wanted and unwanted products of the first modulation could be made without introducing difficulties introduced by selecting the carrier at a higher point. It was found that the thirty-fifth harmonic, having a frequency of 2520 kilocycles fulfilled all the requirements set forth above with respect to the choice of this carrier. The frequency in the lower side-band resulting from the second modulation which corresponds to the first carrier frequency of 2376 kilocycles and the zero component of the original television signal is 144 kilocycles, namely, the difference between the frequencies of the first and second carriers. This reference frequency of 144 kilocycles falls in the television range suitable for transmission over the coaxial cable. The shifted frequencies corresponding to the lower side-band of the 2376-kilocycle carrier modulation lie above this reference frequence of 144 kilocycles and the vestigial upper side-band selected by the band-pass filter from the first modulation products lie below this reference frequency.

A specially designed modulator in accordance with this invention is used for the first modulator in order to effect complete suppression of the first carrier of 2376 kilocycles. This modulator comprises an active vacuum tube on the input of which the wide band of television frequencies are impressed and a passive vacuum tube for suppressing the unmodulated carrier. A modulation component of carrier frequency corresponding to zero frequency components in the television signal does appear in the output of this modulator.

This modulator is disclosed and claimed in Patent 2,273,548, issued February 17, 1942, the application for which was filed September 24, 1940 as a true division of this application.

While the invention is being described in a single embodiment making use of a concentric cable as the transmitting means, it should be understood that in certain of its broader aspects the invention is not limited to cable operation and that some of the features of the invention are of broader application than to transmission in television.

The invention will now be described more in detail with reference to the accompanying drawings:

Figs. 1 and 2, taken together, illustrate schematically a television system embodying this invention; and

Figs. 3 and 4, taken together, show the circuit arrangements of the first and second modulators and the band-pass filter therebetween for passing the lower side-band and vestigial upper side-band from the first modulator.

The illustrative embodiment of the invention shown schematically in Figs. 1 and 2 will now be

described. To illustrate the complete system, Fig. 1 should be placed on the left-hand side of Fig. 2 with the lines L joined together. The circuit elements located at the transmitter are shown in the lower portion of Fig. 1 and those located at the receiver are shown in the lower portion of Fig. 2. The frequency bands present at various points in the circuit and the energy distribution within these bands, sometimes spoken of herein as the shape of the band or the band shape, are shown in the upper portions of Figs. 1 and 2.

The television signal or video signal originates in a light sensitive electric device 1, such as a photoelectric cell or a photoelectric electron multiplier, energized by light under the control of suitable scanning devices. For the system being described, a scanning disc provided with a circle of lenses was used to scan a uniformly moving sound picture film. Each frame was scanned in 240 lines at the rate of 24 frames per second producing a video signal extending from zero frequency to an upper useful frequency of approximately 806 kilocycles. The scanning light energized a photoelectric electron multiplier to produce the video signals.

The major portion of the video signal band is shown by cross-hatched diagram 2. The relative energy content of the various frequency components is shown by the horizontal distance between the vertical line 3, which is a zero reference line, and the line 4. The video signal band, as mentioned above, extends from zero frequency to approximately 806 kilocycles, as indicated by the logarithmic frequency scale on the left-hand side of Fig. 1. A corresponding scale appears on the right-hand side of Fig. 2. This video signal is impressed on a first modulator 5 to modulate a carrier frequency of 2376 kilocycles. Modulator 5 is specially designed to suppress practically completely all unmodulated carrier current. The important frequencies appearing in the output circuit of modulator 5 are a band of frequencies corresponding to the video signal represented by cross-hatched diagram 6 and upper and lower side-bands on either side of the 2376-kilocycle carrier represented by cross-hatched diagrams 7 and 8. The lower side-band extends from approximately 1570 kilocycles up to the carrier frequency 2376 and the upper side-band 8 extends from this carrier frequency up to approximately 3182 kilocycles.

The frequency components in the output of modulator 5 are impressed on a band-pass filter 95 which suppresses the video signal band 6 and a large portion of the upper side-band 8 and transmits the lower side-band 7 and a vestigial side-band represented respectively by the cross-hatched diagrams 9 and 10. The cut-off of filter 95 in the neighborhood of the 2376-kilocycle carrier is represented by line 11 extending to the left of reference line 12. The vestigial side-band extends to approximately 2450 kilocycles.

This lower side-band 9 and vestigial upper side-band 10 are impressed on a second modulator 13 to modulate a carrier frequency of 2520 kilocycles. The important frequencies appearing in the output circuit of modulator 13 are the upper and lower side-bands corresponding to the bands 9 and 10 passed by the filter 95 and the bands 9 and 10. The portion of the lower side-band corresponding to band 9 is represented by cross-hatched diagram 14 and the portion corresponding to the vestigial side-band 10 is represented by cross-hatched diagram 15, these two portions 14 and 15 lying, respectively, above and below 144 kilocycles, which is the component of the lower side-band of the second modulater 13 corresponding to the first carrier of 2376 kilocycles and the zero frequency component of the video signal 2. This lower side-band extends from approximately 70 kilocycles to 950 kilocycles. The portion of the upper side-band corresponding to band 9 is represented by cross-hatched diagram 16 and the portion corresponding to the vestigial side-band 10 is represented by cross-hatched diagram 17. This upper side-band extends from approximately 4089 kilocycles to 4944 kilocycles. Modulator 13 is a balanced modulator which transmits the modulating bands 9 and 10 represented by cross-hatched diagram 96 but suppresses the carrier of 2520 kilocycles.

The frequency components in the output of second modulator 13 are impressed on a low-pass filter 18 which passes bands 14 and 15 and suppresses any 2520-kilocycle second carrier leak, the modulating band 96 and the upper side-bands 16 and 17. The transmitted bands 14 and 15 are represented by cross-hatched diagrams 19 and 20, respectively. The upper cut-off of filter 18 is represented by line 21 extending to the left of zero reference line 22. These transmitted bands 19 and 20 extend from approximately 70 kilocycles to 950 kilocycles.

The transmitted bands 19 and 20 are amplified in amplifier 23 and passed through a line predistortion network 24, another amplifier 25, an aperture equalizer 26, another amplifier 27 and a terminal equalizer 28. The combined attenuating characteristics of network 24 and equalizers 26 and 28 are represented by the uncross-hatched diagram 29 and the shape of the transmitted band is represented by the cross-hatched diagram 30.

The frequency components appearing in the output of equalizer 28 are impressed upon a shaping high-pass filter 31 which narrows the band 30 by suppressing all the frequency components below 100 kilocycles and shaping the components in the neighborhood of 144 kilocycles to effect approximately one-half the effect required by the principles disclosed in Nyquist Patent 1,748,186, supra. The frequency components corresponding to bands 19 and 20 appear in the output of filter 31 with relative energy values or band shape, as represented by cross-hatched diagrams 32 and 33. The lower cut-off of high-pass filter 31 is represented by line 34 extending to the left of zero reference line 35. These bands 32 and 33 are amplified in amplifier 36 and transmitted to the line L which, preferably, is a coaxial cable provided with suitable amplifiers and equalizers to transmit a wide band of frequencies with comparatively little distortion.

It is seen from diagrams 32 and 33 that there is a band of transmitted frequencies on either side of 144 kilocycles. The band 33 above 144 kilocycles corresponds to the whole essential range of the video signals and is a complete side-band, while the band 32 is a vestigial side-band. The component frequencies in the complete side-band, which are complementary to those in the vestigial side-band, are attenuated about one-half enough to compensate for the presence of the vestigial side-band. Filter 31 also adjusts the phase of the transmitted frequency compo-

nents to compensate for phase distortions introduced by preceding circuit elements.

Due to the transmission characteristics of the coaxial cable and included amplifiers, the band shape of the transmitted bands 32 and 33 is changed somewhat during transmission over the coaxial cable. The shape of these bands as they appear at the receiver terminal of coaxial cable L is represented by cross-hatched diagram 37.

This band 37 is passed through high-pass filter 38 and low-pass filter 39. These filters eliminate interfering frequencies outside of the transmitted band 37 and further shape the band in the neighborhod of 144 kilocycles. The shape of the band transmitted by filters 38 and 39 is represented by cross-hatched diagram 40 comprising the portion 41 above 144 kilocycles and the vestigial side-band portion 42 below 144 kilocycles. The cut-off of high-pass filter 38 is represented by line 43 extending to the left of zero reference line 44. The cut-off of low-pass filter 39 is represented by line 45, also extending to the left of zero reference line 44. This band 40 extends from 100 kilocycles to approximately 950 kilocycles.

The band 40 is amplified in amplifier 46 and passed through an aperture equalizer and line restoring equalizer 47. The attenuating characteristics of equalizer 47 are represented by uncross-hatched diagram 48 and the shape of the transmitted band is represented by cross-hatched diagram 49 composed of complete side-band 50 and a vestigial side-band 51.

The band 49 comprising bands 50 and 51 is impressed on a first demodulator 52 to modulate a carrier frequency of 2520 kilocycles. This demodulator 52 is designed to suppress the 2520-kilocycle carrier. The important frequencies appearing in the output of demodulator 52 are an upper and lower side-band and the modulating band 49 represented by cross-hatched diagram 97. The lower side-band may be considered as comprising a band extending below 2376 kilocycles and a vestigial side-band extending above 2376 kilocycles represented, respectively, by cross-hatched diagrams 53 and 54. The bands 53 and 54 correspond, respectively, to the portions 50 and 51 of the modulating band 49. These two bands extend from approximately 1570 kilocycles to 2420 kilocycles. The upper side-band is represented by cross-hatched diagram 55. This band extends from approximately 2620 kilocycles to 3470 kilocycles.

The frequency components in the output of demodulator 52 are impressed on a band-pass filter 56, an amplifier 57 and a 2520-kilocycle band elimination filter 58. The band-pass filter 56 passes the bands 53 and 54 which make up the lower side-band of demodulator 52 represented, respectively, by cross-hatched diagrams 98 and 99, and suppresses the upper side-band 55 and greatly attenuates any 2520-kilocycle carrier leak. The upper and lower cut-offs of filter 56 are represented by lines 100 and 59, respectively. The band elimination filter 58 completely suppresses for all practical purposes any remainder of the 2520-kilocycle carrier and effects a slight final shaping of the bands 60 and 61 in the neighborhood of the 2376-kilocycle carrier in accordance with the principles of the Nyquist patent, supra. The attenuation characteristic of the band elimination filter 58 is represented by line 62. The final shaping effected by this filter 58 is inherent in its attenuation characteristic and is compensated for by under-shaping in high-pass filter 38.

The finally shaped bands 60 and 61 are impressed on a second demodulator 63 to modulate a carrier frequency of 2376 kilocycles applied in proper phase relation to the frequencies of the modulating bands 60 and 61 to produce a signal current according to the Nyquist principle. The important frequencies appearing in the output of demodulator 63 are the video signal which is substantially identical with that impressed on the first modulator 5 except that it is equalized to compensate for aperture distortion in the scanning devices, represented by the cross-hatched diagram 64, a band of frequencies corresponding to the modulating bands 60 and 61 represented by cross-hatched diagram 65, and an upper side-band represented by cross-hatched diagram 66. The frequencies in the video signal band 64 extend from zero frequency to about 806 kilocycles. The frequencies in band 65 extend from about 1570 kilocycles to 2420 kilocycles. The frequencies in the upper side-band 66 extend from approximately 3946 kilocycles to 4796 kilocycles. The second demodulator 63 is specially designed to suppress the carrier frequency or 2376 kilocycles completely for all practical purposes.

The frequency components in the output of second demodulator 63 are impressed on a low-pass filter which passes only the video signal band represented by cross-hatched diagram 68. This video signal band 68 is applied to cathode ray tube 69 to control the brightness of the scanning spot on the fluorescent screen. This video signal band 68 has a form suitable for compensating for the finite size of spot in the cathode ray tube, this compensating shape resulting from the operation of the aperture equalizer 47.

The 2376-kilocycle and 2520-kilocycle carrier frequencies accurately spaced are derived from an accurately controlled carrier supply source 70. From this source 70 a 72-kilocycle frequency is first obtained. This 72-kilocycle standard frequency is passed through a purifying crystal band-pass filter 71 and impressed on a harmonic generator 72. The thirty-third harmonic or 2376-kilocycle carrier is selected from the output of harmonic generator 72, passed through crystal band-pass filter 73 and applied to the first modulator 5. The thirty-fifth harmonic or 2520-kilocycle carrier is also selected from the output of harmonic generator 72, passed through crystal band-pass filter 74 and applied to the second modulator 13.

A 5.76-kilocycle frequency for controlling the sweep circuits of the cathode ray tube 69 is obtained directly from a synchronizing impulse producer 75 associated with the scanning disc. This 5.76-kilocycle frequency from synchronizing impulse producer 75 is used to modulate a portion of the standard 72-kilocycle frequency from filter 71 in modulator 76. The 72-kilocycle carrier and the lower side-band frequency of 66.24 kilocycles resulting from the modulation are selected by double band crystal filter 175, which frequencies are impressed on the coaxial cable L at the transmitting terminal and transmitted to the receiver.

At the receiving terminal the 72-kilocycle carrier and the 66.24-kilocycle side-band frequency are selected from the coaxial cable L by the double band crystal filter 77 and impressed on demodulator 78, from the output of which the 72-kilocycle frequency is selected by crystal band-pass filter 79, and the lower side-band frequency

of 5.76 kilocycles is selected by the crystal band-pass filter 80. The 5.76-kilocycle frequency is used to control the sweep circuit generator 81 which furnishes the sweep currents for cathode ray tube 69. The 72-kilocycle frequency from filter 79 is impressed on harmonic generator 82. From this harmonic generator 82 the 2520-kilocycle carrier is selected by crystal band-pass filter 83 and applied to the first demodulator 52 and the 2376-kilocycle carrier is selected by crystal band filter 84 and applied to the second demodulator 63 in proper phase. The phase may be adjusted manually, the proper adjustment being indicated by the appearance of the produced image on the screen of the cathode ray tube 69.

The program frequency band is transmitted as modulations of an 84-kilocycle carrier from carrier source 70. The program frequency band is derived from the sound track on the film in sound reproducer 85. The 84-kilocycle program carrier frequency is passed through crystal band-pass filter 86 and, together with the program frequency band from sound reproducer 85, is impressed on modulator 87. The lower side-band resulting from the action of modulator 87 is selected by band-pass filter 88 and impressed on the coaxial cable L at the transmitting terminal and transmitted to the receiver.

At the receiving terminal the program side-band is selected by band-pass filter 89 and an 84-kilocycle carrier selected by band-pass filter 91 from carrier supply source 90 together are impressed on demodulator 92. The program frequency band is selected from the output of demodulator 92 by band-pass filter 93 and applied to loud-speaker 94 for program reproduction.

The relative positions of the program band, the 72-kilocycle standard frequency, and the synchronizing 66.24-kilocycle side-band frequency with respect to the transmitted television band 37 on the coaxial cable L are shown below the cross-hatched diagram 37 in Fig. 2. Two pilot channels are also provided, as indicated in Fig. 2, at 1024 kilocycles and 60 kilocycles for controlling the gains of the coaxial cable amplifiers.

Referring now to Figs. 3 and 4, the circuits of the first modulator 5, band-pass filter 95, second modulator 13 and the connection to the first modulator 5 of the light sensitive electric device 1 in the form of a photoelectric electron multiplier will be described. The coaxial cable 171 at the right side of Fig. 3 and the coaxial cable 172 at the left side of Fig. 4 are portions of the same cable.

As hereinbefore described the light signals coming from the scanning disc fall upon the photoelectric cathode of the electron multiplier 101 which transforms them into video signals which are transmitted from the multiplier 101 by means of a section of double shielded coaxial cable 102 to the first modulator 5. In the input circuit of the first modulator 5 the condensers 103, 104 and 105 and coil 106 form a low-pass network which when terminated in the resistance 107 nominally 1,000 ohms present a 1000-ohm impedance to the terminals of the electron multiplier at video frequencies. The vacuum tubes 108 and 109 in the first modulator 5 are so-called space charge pentodes. After the cathode the first electrode is a space charge grid, hereafter known as the net electrode. The next electrode is the ordinary control grid, the third a screen grid, and the last the plate. The video signal is placed on the control grid of vacuum tube 108. The 2376-kilocycle carrier frequency comes in on a coaxial cable 110 to a potentiometer 111 and is applied across the net electrodes of both tubes 108 and 109. This carrier circuit is bridged by a resistance 112 in series with a thermocouple 113 for the purpose of reading the carrier frequency voltage applied. The positive direct current voltage on the net electrodes is supplied by the battery 114 through the filter consisting of condensers 115 and 116 and coils 117 and 118. The passive tube 109 serves the sole purpose of balancing out the carrier frequency in the output of the modulator 5. Condensers 119 and 120 and resistance 121 are adjusted to make the impedance facing the control grid of the passive tube 109 equal to that facing the control grid of the active tube 108 at carrier frequencies. The negative control grid bias of the passive tube 109 is furnished by battery 122 and may be adjusted by means of potentiometer 123 to make the carrier frequency transmission of the passive tube 109 equal to that of the active tube 108. The negative bias on the control grid of the active tube 108 is furnished by battery 124. The positive screen bias is furnished by the tap on battery 125 through coil 126 and the screen grids are shunted by condenser 127. The two plates are shunted by resistances 128 and 128 and connected to an output network consisting of condensers 130 and 131 and transformer 132. Condenser 130 really consists of two condensers, one of which subtracts capacity from one plate circuit as it is added to the other. The law of variation governing these two condensers is such that the total series capacitative impedance across both plates is at all times kept constant. Coil 133 and condenser 134 form a circuit tuned to the second harmonic of the 2376-kilocycle carrier frequency to aid in its suppression. It will be seen that there are two controls affecting the balance of carrier frequency at the output of the first modulator, namely, the potentiometer 123 which varies the gain of the passive tube 109 and the condenser 130 which act as a phase balance in the output circuits. By means of this double adjustment it is possible to suppress the unwanted carrier frequency in the output of the modulator by approximately 80 decibels. The carrier supplied to this modulator 5 modulates the video signal coming from the electron multiplier 101 and its output contains two complete side-bands. It is to be noted that since the input circuits to the modulator transmit all the way down to direct current, any direct current coming from the electron multiplier will unbalance the modulator causing unmodulated carrier frequency to flow in its output which is exactly proportional to the direct current in the input circuit. This makes it possible for information concerning the average background of the picture to be transmitted. The band filter 135 selects the lower side-band of the carrier and a small portion of the upper sideband. The input network of the second modulator 13 consisting of transformer 136, condensers 137 and 138 and resistances 139 and 140 is similar to the output network of the first modulator 5. The second modulator 13 is a conventional balanced modulator employing power pentodes 176 and 177. The signal frequency is applied to the control grids of the two tubes in series and the carrier frequency is applied to the control grids of the two tubes in parallel. The 2520-kilocycle carrier frequency is applied through a parallel tuned circuit consisting of condenser 141 and coil 142 across the resistance 143. Potentiometer

144 allows a balance to be obtained against the carrier frequency of the second modulator 13 in its output circuit. Plate and screen potentials for the tubes are obtained from a 250-volt supply and applied to the screens through coil 145 and to the plates through coil 146. Condensers 147 and 148 in conjunction with coils 145 and 146 act as power filters for supplying the screen and plate potentials. Grid bias is obtained by the drop across resistance 153 and the parts of potentiometer 144. The output circuit consists of transformer 149 shunted by resistances 150 and 151 on its high impedance winding and shunted by resistance 152 on the low impedance winding.

In order to fully disclose the method of construction of the illustrative embodiment of the invention hereinbefore described, the values of certain of the circuit elements will now be given. Referring particularly to Fig. 3, condenser 103 has a capacitance of 184.9 micro-microfarads less the inherent capacitance of the section of coaxial cable 102 and the electron multiplier 101. The condenser 104 has a capacitance of 73.95 micro-microfarads. Condenser 105 has a capacitance of 40.19 micro-microfarads less the inherent capacitance of active tube 8. Coil 106 has an inductance of 125.8 microhenries. Resistance 107 has a value of 1,000 ohms. Vacuum tubes 108 and 109 are identical and preferably are Western Electric Code No. 7575F vacuum tubes. Potentiometer 111 has a resistance of 400 ohms and resistance 112 has a value of 1,800 ohms. The thermocouple 113 has a resistance of 500 ohms. Battery 114 is of 10.5 volts. Condensers 115 and 116 each have a capacitance of .03 microfarad. Coils 117 and 118 each have an inductance of 1 millihenry. Condenser 119 is adjustable and has a nominal capacitance of 50 micro-microfarads. Condenser 120 has a capacitance of 20 micro-micro-farads. Resistance 121 has a value of 1,000 ohms. Battery 122 is of 9 volts. Battery 124 is of 1.5 volts. The total voltage of battery 125 is of 250 volts and the lower portion of 160 volts. Coil 126 has an inductance of 1 millihenry. Condenser 127 has a capacitance of .7 microfarad. Resistances 128 and 129 each have a value of 3,000 ohms. The left-hand winding of transformer 132 has an inductance of 243 microhenries and right-hand windings in parallel have an inductance of 20.2 micro-henries. Condensers 130 and 131 are adjustable and in parallel with the tube capacities are set to tune the left side windings of transformer 132 to 1,862 kilocycles. Coil 133 has an inductance of 100 microhenries and condenser 134 has a capacitance of 25 micro-microfarads, the condenser 134 being adjusted to form a tuned circuit with coil 113 tuned to a frequency of 4,752 kilocycles.

Referring now to Fig. 4, the band filter 135 comprises two series elements in the form of parallel tuned circuits 160 and 161 and a shunt element in the form of a parallel tuned circuit 162. Tuned circuit 160 consists of a coil 163 having an inductance of 149.6 microhenries and a condenser 164 set to tune this circuit 160 to a frequency of 1,000 kilocycles. Tuned circuit 161 consists of a coil 165 having an inductance of 21.0 microhenries and a condenser 166 set to tune this circuit 161 to a frequency of 2,625 kilocycles. Tuned circuit 162 consists of a coil 167 having an inductance of 55.3 microhenries and a condenser 168 set to tune circuit 162 to a frequency of 2,350 kilocycles. Condenser 169 has a capacitance of 344.8 micro-microfarads and condenser 170 a capacitance of 195 micro-microfarads.

Still referring to Fig. 4, the left-hand winding of transformer 136 has an inductance of 47 microhenries and the right-hand winding has an inductance of 278 microhenries, each of the two condensers making up condenser 137 having a capacitance of 10 micro-microfarads. Condensers 137 and 138 in parallel with the inherent tube capacities, are set to form a tuned circuit with the right-hand winding of transformer 136 tuned to a frequency of 1,790 kilocycles. Resistances 139 and 140 each have a value of 3,000 ohms. Condenser 141 and inductance coil 142 are adjusted to be antiresonant at 2,520 kilocycles. Resistance 143 has a value of 100 ohms. Potentiometer 144 has a resistance of 150 ohms while the condensers connected to either terminal of resistance 144 each has a capacitance of .7 microfarad and the resistance connected to the variable contact of resistance 144 has a value of 500 ohms. Each of resistances 150 and 151 has a value of 2,140 ohms. Resistance 152 has a resistance of 260 ohms. Tubes 176 and 177 are identical and preferably are Western Electric Code No. 7629 vacuum tubes.

The high-pass filters 31 and 38 are constructed each with amplitude attenuating sections and phase adjusting sections according to well-known filter design principles. Sufficient sections of each kind are used to produce the band shapes described hereinbefore.

What is claimed is:

1. An electro-optical image producing system comprising means to produce a video signal having frequency components extending from a very low frequency to several hundred kilocycles, means to produce a control frequency lying within the range of frequencies constituting the video signal, means to produce two carrier frequencies which constitute adjacent odd harmonics of said control frequency, means to modulate the lower of said carrier frequencies with said video signals, means to select and transmit only the lower side-band and vestigial upper side-band resulting from said modulation, means to modulate said higher carrier with said transmitted side-bands, means to select only the lower side-band resulting from said second modulation, and means to transmit said last selected side-band and produce a television image therefrom.

2. A television system comprising means to produce a video signal having components extending from a very low frequency to several hundred kilocycles, a first modulator comprising an active tube and a passive tube each having a cathode, a net electrode, a control grid, a screen grid and a plate, means to impress said video signal on the cathode and control grid of said active tube only, means to impress a first carrier wave on the cathodes and net electrodes of both said tubes in parallel, means to impress a direct current potential on the screen grids of both said tubes in parallel, means to impress direct current biasing potentials on the control grids of both said tubes, means to independently adjust the biasing potential on the control grid of said passive tube and the alternating current impedance between the cathodes and the plates of both said tubes to completely suppress any component of unmodulated carrier current in the output circuit of said modulator, a band pass filter transmitting the entire lower side-band and a portion of the upper side-band of frequencies received from said first modulator and

suppressing the rest of said upper side-band, a second modulator comprising means to modulate a second carrier current with the side-band frequencies transmitted by said band pass filter and suppress said second carrier, means to produce a second carrier of frequency slightly higher than the highest upper side-band frequency transmitted by said band pass filter, and means to transmit a portion only of the lower side-band produced by said second modulator and suppress the other side-band and differently attenuate the transmitted side-band on either side of the side-band frequency corresponding to the frequency of said first-mentioned carrier current.

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