March 7, 1944. L. W. MORRISON, JR 2,343,568

ELECTRO-OPTICAL SIGNALING

Filed Jan. 10, 1941 3 Sheets-Sheet 1

FIG. 1

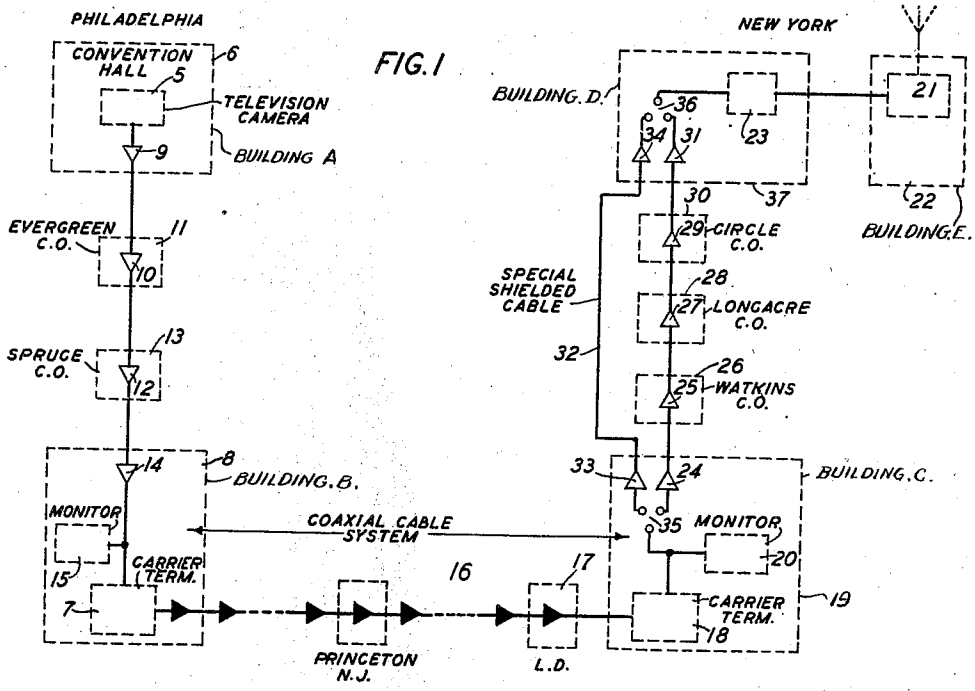

FIG. 2

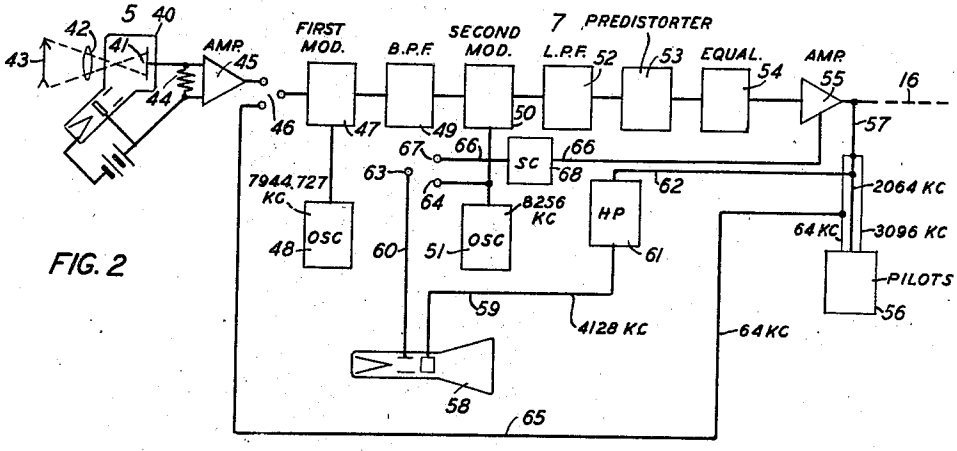

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FIG. 3

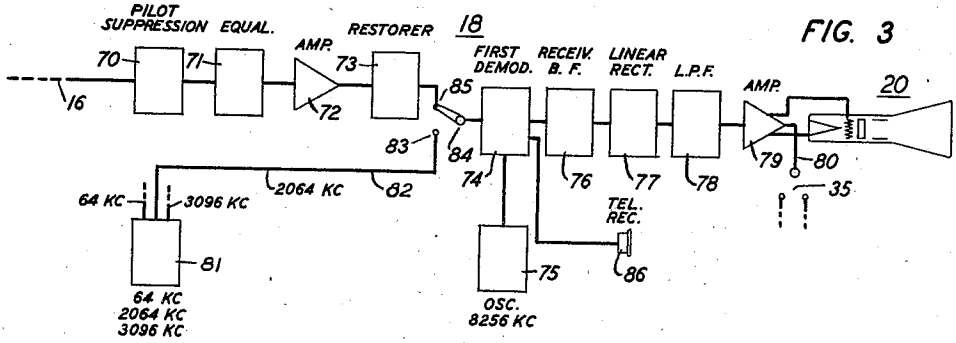

FIG. 4

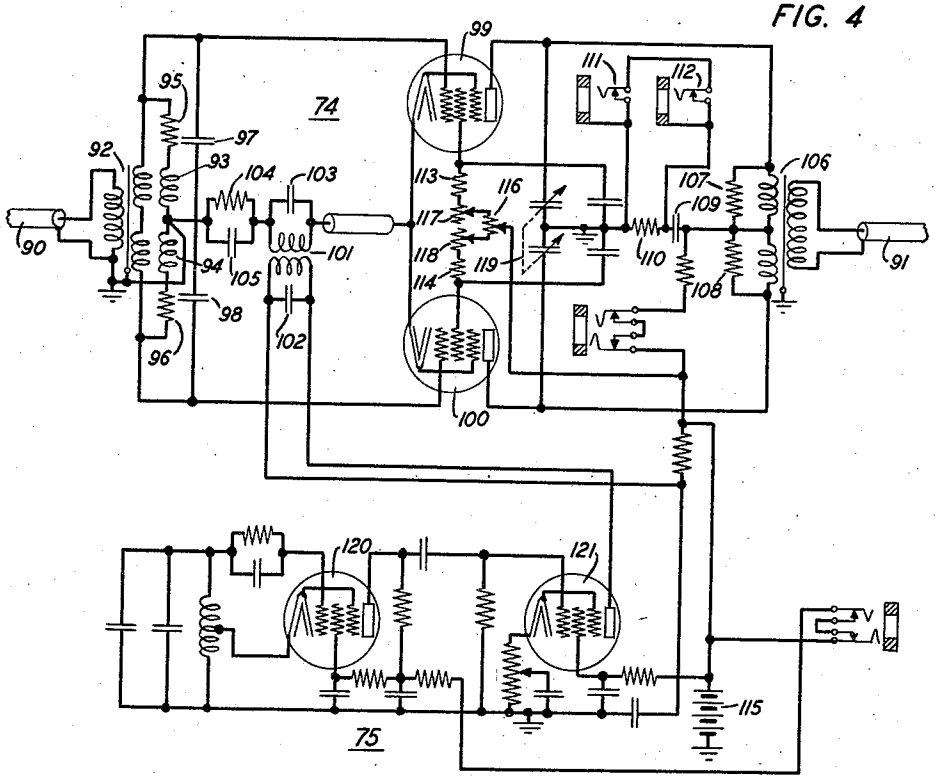

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FIG. 5

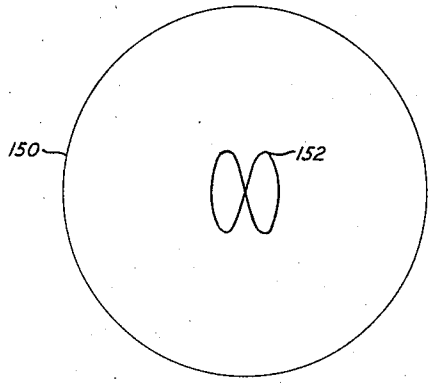


FIG. 6

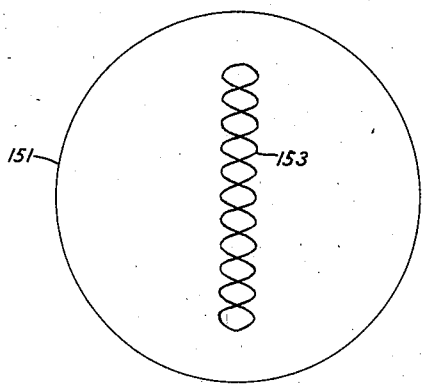
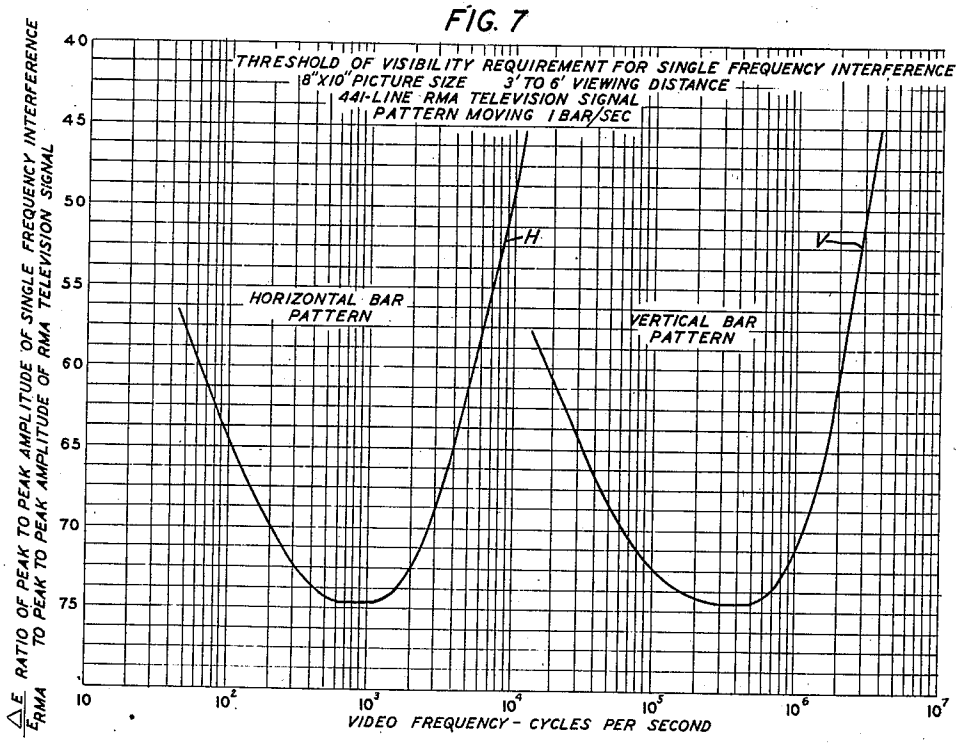


FIG. 7



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Patented Mar. 7, 1944

2,343,568

UNITED STATES PATENT OFFICE

2,343,568

ELECTRO-OPTICAL SIGNALING

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Application January 10, 1941, Serial No. 373,925

10 Claims. (Cl. 178—6)

This invention relates to signaling and more particularly to television and high speed picture transmission.

An object of the invention is to improve the transmission of signals for such types of transmission as television and high speed picture transmission over long circuits which require a large number of line amplifiers.

In recent years a new type of wide band signaling circuit has been developed utilizing a coaxial cable. Such a system is described in considerable detail in a paper by M. E. Strieby entitled "Coaxial cable system for television transmission" and published in the Bell System Technical Journal for July 1938, beginning on page 438.

It was desired to use such a transmission circuit for the transmission of television signals of the kind now approved by the R. M. A. (Radio Manufacturers' Association) Standards Committee. Such approved television signals include a video band of frequencies extending from about 30 cycles per second to 2800 kc. The symbol kc. wherever used in this application signifies kilocycles per second. Such a coaxial cable system cannot be used to transmit the video band directly. Therefore it becomes necessary to shift this band to a position in the frequency spectrum which can be transmitted over the coaxial cable system without undue distortion.

Applicant was confronted with the problem of transmitting such a video band over a coaxial cable system including a large number of vacuum tube amplifiers with such a small amount of distortion that the received video band could be used to produce television images of satisfactory quality. In the solution of this problem applicant conceived the invention of the present application.

A feature of this invention is a double modulation carrier current system operating at such carrier frequencies and at such current levels in the cable amplifiers that interfering frequency components are produced in the amplifiers but at such frequencies that they do not unduly detract from the quality of the images produced in the receiver. As a result of this invention television transmission over long coaxial cable systems is made economically feasible because the amplifiers are operated at a high current level which could not be used in systems not embodying this invention.

In a specific coaxial cable system with which applicant is concerned the frequency band available for the transmission of signals extended from 64 kc. to approximately 3100 kc. This system exhibited a relatively large amount of phase distortion through the lower frequency portion of this region so that the lowest frequency suitable for television transmission purposes is approximately 150 kc. The amplifiers for this cable system had been designed primarily for telephone transmission extending only to 2064 kc. and consequently the feedback had been allowed to fall off progressively above this point. Therefore it is advantageous to transmit the main side band over the cable in an upright position so that the high energy region of the television signal is transmitted through the amplifiers at relatively low frequencies where less distortion occurs.

For well-known reasons so-called vestigial side-band transmission is employed. From previous studies it was known that too narrow a vestigial side band caused large phase distortion in the associated vestigial shaping networks with an attendant increase in cost of equalization. It is therefore desirable to use as large a vestigial side band as possible providing the main side band is not reduced too much because of the finite width of the total band which can be transmitted over the coaxial cable system.

In the specific system now being considered a vestigial to main side-band width ratio of four per cent has been found to be a good compromise between these two factors.

In view of the above noted conditions where the band available for television transmission over the coaxial cable system extends from 150 kc. to 3100 kc., the width of the main side band is approximately 2800 kc. and the width of the vestigial side band is approximately four per cent of the main side band or 112 kc., the first carrier frequency as it appears on the coaxial cable system must be positioned somewhere between 262 kc. and the neighborhood of 300 kc. In order to avoid the complication of using elaborately balanced modulators to suppress the wide band video signals the first and second carrier frequencies at the transmitter were so chosen that the lower side band resulting from the first modulation did not overlap the video band and the lower side band resulting from the second modulation with the lower side band and vestigial upper side band of the first modulation occupied the frequency band available for transmission over the coaxial cable system. These requirements indicate that the first and second carrier frequencies should be in the neighborhood of 8000 kc.

But these are not the only requirements. In

connection with the specific coaxial cable system being considered pilot frequencies were employed to control the gain of the amplifiers to compensate for changes in temperature of the coaxial cable and associated apparatus. These pilot frequencies occur at 64 kc., 2064 kc. and 3096 kc. Since the intermediate and upper pilot frequencies lie within the band of television frequencies transmitted over the coaxial cable system, they must be suppressed before reaching the image producer or they will cause distortion in the received picture. Applicant was therefore confronted with the problem of selecting such carrier frequencies that these frequencies on the coaxial cable system were to lie between energy concentrations in the frequency spectrum on the cable system corresponding to line scanning frequencies of the video spectrum.

By taking notice that single frequency interference in the received video band, which occurs between energy concentrations at harmonics of the picture line scanning frequency, causes less noticeable distortion in the received picture than single frequency interference which coincides with such energy concentrations, applicant has been able to choose his carrier frequencies so that the amplifiers may be worked at a higher level than was heretofore known to be possible. In the specific case being considered where a large amount of unmodulated first carrier frequency is transmitted along with the modulated side band, applicant has so selected his carrier frequencies that the second harmonic of the frequency on the coaxial cable system corresponding to the first carrier frequency occurs nearly midway between two energy concentrations corresponding to two energy concentrations at harmonics of the picture line scanning frequency. Such a frequency allocation permits the requirement of the second harmonic distortion of the cable amplifier to be reduced by a considerable amount.

In the specific television system being considered the following frequency allocation was arrived at in accordance with this invention:

Video band		30 cycles to 2800 kc. (RMA type signal)
Line scanning frequency (f_L)	kc.	13.23
First modulator carrier frequency (fc_1)	do	7944.727
Second modulator carrier frequency (fc_2)	do	8256
Frequency of first carrier as transmitted (fo)	do	311.273
Low frequency pilot	do	64
Intermediate frequency pilot	do	2064
High frequency pilot	do	3096
Side bands as transmitted (approx.)	kc.	200 to 3100

In this system the second harmonic of the first carrier on the cable ($2fo$=622.546 kc.) is displaced from the position midway between the twenty-third and twenty-fourth harmonics of the line scanning frequency as they appear on the cable

($23f_L+\frac{1}{2}f_L+fo=23\times13.23+\frac{1}{2}\times13.23+311.273=$ 622.178 kc.)

by only 368 cycles. Such an allocation permits of increasing the current level in the line amplifiers 23.5 decibels over what could be used if such harmonic coincided with an energy concentration frequency on the coaxial cable system. In other words the second harmonic lies near the center of the valley between energy concentrations. The intermediate frequency pilot at 2064 kc. also falls only 245 cycles from the mid-frequency between energy concentrations on the cable corresponding to the one hundred and thirty-second and one hundred and thirty-third harmonics of the line scanning frequency.

A further advantage of this allocation resides in the ease with which the oscillators furnishing the first and second carrier frequencies may be adjusted. The pilot frequencies are all readily available at the carrier terminal stations where the carrier oscillators are located.

The proper adjustment of the second carrier oscillator is first determined by comparing its frequency with the second harmonic of the 2064 kc. pilot frequency. Power from the second carrier oscillator is impressed on one set of deflecting elements of a cathode ray oscilloscope while the second harmonic of the 2064 kc. pilot frequency, namely, 4128 kc. is impressed on the coordinate set of deflecting elements. The frequency of the oscillator is then adjusted to give a stationary double loop pattern along the oscillator axis of the oscilloscope thus indicating that the frequency of the oscillator is four times that of the 2064 kc. pilot or 8256 kc.

The proper adjustment of the first carrier oscillator is next determined by comparing the main lower side band of the second modulator with the second harmonic of the 2064 kc. pilot, when power from the 64 kc. pilot is used as the modulating frequency of the first modulator in place of the video signals. After the frequency of the second carrier oscillator has been adjusted as described just above, the lower main side band of the second modulator is impressed on one set of deflecting elements of the above-mentioned cathode ray oscilloscope while as before the second harmonic of the 2064 kc. pilot is impressed on the coordinate set of deflecting elements. The frequency of the first oscillator is then adjusted to give a stationary eleven-loop pattern along the side-band frequency axis of the oscilloscope, thus indicating that the eleventh harmonic of the main lower side band is equal to the second harmonic of the 2064 kc. pilot. With this adjustment the frequency of the first carrier oscillator is very nearly 7944.727 kc. The relationship between the various frequencies involved is indicated by the following equation:

$$fC_2-(fc_1-fp_1)=\frac{2f_{p2}}{11} \quad (1)$$

wherein the symbols are the same as used hereinbefore. It follows from Equation 1 that

$$fC_1=fc_2+f_{p1}-\frac{2f_{p2}}{11} \quad (2)$$

Therefore,

$$fC_1=8256+64-\frac{2\times2064}{11} \quad (3)$$

$$fC_1=7944.727+\text{kc} \quad (4)$$

From the foregoing it is seen that applicant has embodied his invention in a television system having advantages for a number of different reasons. It is not necessary always to take into account all of these reasons to gain benefits from applicant's invention. For example, there may be no pilot frequencies within the region available for television transmission; still there is a real advantage in choosing the carrier frequencies so that the harmonics of the frequency on the transmission circuit corresponding to the first carrier frequency falls between energy concen-

trations on the transmission circuit corresponding to harmonics of the picture line scanning frequency.

In order to assist in obtaining the advantages of applicant's invention illustrative relationships will now be set forth in the form of equations using the symbols hereinbefore defined. The symbols m, n, n', k and k' used in these equations denote integers. The following relationships should be closely approximated in order to obtain the advantages of applicant's invention with respect to

(a) Second order modulation in the amplifiers,

$$f_O=\left(n+\frac{1}{2}\right)f_L=fc_2-fc_1 \quad (5)$$

(b) Third order modulation equation,

$$2f_O=\left(n'+\frac{1}{2}\right)f_L=2(fc_2-fc_1) \quad (6)$$

(c) Pilot frequency elimination,

$$f_p-f_O=\left(m+\frac{1}{2}\right)f_L \quad (7)$$

$$f_O=f_p-\left(m+\frac{1}{2}\right)f_L \quad (8)$$

(d) Second order modulation and pilot frequency elimination simultaneously,

$$f_p=\left(m+\frac{1}{2}\right)f_L+f_O \quad (9)$$

$$=\left(m+\frac{1}{2}\right)f_L+\left(n+\frac{1}{2}\right)f_L \quad (10)$$

$$=(m+n+1)f_L \quad (11)$$

$$=Kf_L \quad (12)$$

where

$$K=(n+n+1)=\text{an integer} \quad (13)$$

and

(e) Pilot elimination and third order modulation,

$$f_p=\left(m+\frac{1}{2}\right)f_L+\frac{\left(n'+\frac{1}{2}\right)f_L}{2} \quad (14)$$

$$=\left(m+\frac{1}{2}+\frac{n'}{2}+\frac{1}{4}\right)f_L \quad (15)$$

$$=\left(K'+\frac{3}{4}\right)f_L \quad (16)$$

where

$$K'=m+\frac{n'}{2}=\text{an integer} \quad (17)$$

This invention will now be described more in detail having reference to the accompanying drawings.

Fig. 1 illustrates schematically a system embodying applicant's invention.

Fig. 2 illustrates the circuit elements located principally at the transmitting carrier terminal of Fig. 1.

Fig. 3 illustrates the circuit elements located principally at the receiving carrier terminal of Fig. 1.

Fig. 4 shows details of the circuit of the first demodulator and oscillator of Fig. 3.

Fig. 5 shows the pattern appearing on the oscilloscope when the second carrier oscillator is properly adjusted.

Fig. 6 shows the pattern appearing on the oscilloscope when the first carrier oscillator is also properly adjusted.

Fig. 7 illustrates single frequency interference threshold data for the specific television system disclosed herein by way of illustration.

The specific embodiment of the invention described hereinbefore has been used experimentally in connection with a coaxial cable system installed between New York city and Philadelphia. The geographical layout of such system is shown in Fig. 1. As shown in that figure, the television transmitter is located in Philadelphia and the receiver in New York city. A television camera 5 located in building A indicated by block 6 produces video signals which are transmitted over a special circuit adapted to transmit the video band to transmitting carrier terminal equipment 7 located in building B indicated by block 8. This circuit comprises an amplifier 9 at building A, an amplifier 10 at the Evergreen central office 11, an amplifier 12 at the Spruce central office 13 and an amplifier 14 at building B. Cathode ray monitoring equipment 15 for producing a picture from the video signals is also provided at building B.

At the carrier terminal 7 the video band is shifted by modulation to a frequency range suitable for transmission over the coaxial cable system 16. This coaxial cable system comprises twenty amplifiers located at five-mile intervals between building B and the Long Lines building 17. A section of coaxial cable extends from the Long Lines building 17 to the receiving carrier terminal equipment 18 in building C, indicated by the block 19, in New York city. At building C a cathode ray monitoring equipment 20 is located for observing the pictures produced by the detected video band.

Provision is also made to transmit this detected video band to a radio broadcasting station 21 located at building E, indicated by block 22, in New York city by way of a television switching station 23 located in building D, indicated by block 37, in New York city. Alternative circuits extend from building C to building D, both of which circuits are especially adapted to transmit the video band. One of these circuits comprises amplifier 24 in building C, an amplifier 25 at the Watkins central office 26, an amplifier 27 at the Longacre central office 28, an amplifier 29 at the Circle central office 30 and an amplifier 31 at building D. The other circuit comprises a specially shielded cable 32 provided with an amplifier 33 at building C and an amplifier 34 at building D. Either one or the other of these alternative circuits may be used by suitable connections at terminals 35 and 36.

Television camera 5 shown also in Fig. 2 comprises a cathode ray tube 40 which has a photoelectric mosaic screen 41 and suitable scanning circuits to produce R. M. A. Standard video signals. An image of the object being scanned is projected on the screen 41 by lens 42, the object being represented by the arrow 43. Video signals appear across resistance 44 and after amplification in amplifier 45 are impressed on the carrier terminal equipment 7 by suitable connections at terminal 46. The video signals may be produced by any other suitable type of scanner.

Still referring to Fig. 2 this video signal is impressed on a first modulator 47 to modulate a carrier frequency of 7944.727 kc. produced by oscillator 48. Modulator 47 is especially designed to transmit a controlled amount of unmodulated first carrier frequency along with the side bands corresponding to the video signals. The important frequencies appearing in the output circuit of modulator 47 are a band of frequencies corresponding to the video signals, upper and lower

side bands on each side of the 7944.724 kc. carrier and a controlled amount of this carrier, the peak to peak amplitude of which is equal to about twice the peak to peak amplitude of the video envelope. The lower side band extends from approximately 5144 kc. upwards to the neighborhood of the carrier. The upper side band extends upwards from the neighborhood of the carrier to approximately 10,744 kc.

The frequency components in the output of the first modulator 47 are impressed on a band-pass filter 49 which suppresses the video signal and most of the upper side band and transmits the lower side band and a vestigial side band comprising about four percent of the upper side band. The vestigial side band extends to approximately 8056 kc.

The lower side band and the upper vestigial side band are impressed on a second modulator 50 to modulate a carrier frequency of 8256 kc. produced by oscillator 51. The important frequencies appearing in the output circuit of modulator 51 are the upper and lower side bands corresponding to the modulating frequencies and the modulating frequencies themselves. Modulator 50 is a balanced modulator which suppresses the second carrier frequency. The lower side band comprises a component at 311.273 kc. corresponding to the first carrier frequency, a main side band extending to about 3100 kc. corresponding to the lower side band from the first modulator and a vestigial side band extending down to about 200 kc. corresponding to the vestigial side band from the first modulator. The upper side band extends approximately from 13,400 kc. to 16,312 kc.

The frequency components in the output circuit of modulator 50 are impressed on a low-pass filter 52 which passes the frequencies in the lower side band only and suppresses any carrier leak from the second modulator 50, the modulating frequencies and the upper side band. These transmitted bands, as noted above, extend from about 200 kc. to 3100 kc.

The transmitted bands are passed through a predistorter network 53 and a phase and attenuation equalizer 54. After suitable amplification in amplifier 55 they are impressed on the coaxial cable system 16. It should be remembered that the amplitude of the unmodulated component of the first carrier frequency at 311.237 kc. is large compared to the amplitude of the video envelope. Therefore, as will appear later, there is an appreciable amount of second order modulation of this frequency produced in the amplifiers, particularly as the number of amplifiers is increased. By allocating the frequencies according to this invention, a larger amount of second order modulation may be tolerated than would otherwise be the case.

The three pilot frequencies are impressed on the coaxial cable system 16 from a source 56 through circuit 57. As hereinbefore noted the proper adjustment of the frequencies of oscillators 51 and 48 is indicated by comparison with certain of the pilot frequencies. The arrangement of effecting this comparison is shown in Fig. 2. A cathode ray oscilloscope 58 having a vertical deflecting circuit 60 and a horizontal deflecting circuit 59 is provided for this purpose. The second carrier frequency from oscillator 51 is first adjusted by comparing the frequency from oscillator 51 with the second harmonic of the 2064 kc. pilot produced in harmonic producer 61. The 2064 kc. is impressed on the harmonic producer 61 by circuit 62. The 4128 kc. frequency from this harmonic producer is impressed on the horizontal deflecting circuit 59 while the carrier frequency from oscillator 51 is impressed on the vertical deflecting circuit 60 by connecting the terminal 63 to terminal 64. The presence of a stationary double loop pattern along the horizontal axis on the oscilloscope screen indicates the proper adjustment of the frequency of oscillator 51. This frequency is four times that of the 2064 kc. pilot or 8256 kc.

With the frequency of oscillator 51 so adjusted the first carrier frequency from oscillator 48 is next adjusted by comparing the main lower sideband frequency from the second modulator 50 with the second harmonic of the 2064 kc. pilot, when the 64 kc. pilot is impressed on the input circuit of the first modulator 47. The 64 kc. pilot is supplied over circuit 65 through connection 46 to the input of modulator 47. The main lower side-band frequency from the monitoring output of amplifier 55 is impressed on vertical deflecting circuit 60 over circuit 66 which includes selective circuit 68, by connections between terminals 63 and 67. Selective circuit 68 is selective of 375.273 kc., the eleventh harmonic of which is almost exactly equal to the second harmonic of the 2064 kc. pilot. The presence of a stationary eleven-loop pattern along the vertical axis on the oscilloscope screen indicates the proper adjustment of the frequency of oscillator 48. This frequency is very nearly 7944.727 kc. when the 64 kc. and 2064 kc. pilots are adjusted to their normal values.

The shape of the double loop pattern 152 appearing on the screen of oscilloscope 58 when oscillator 51 is properly adjusted is shown in Fig. 5 and the shape of the eleven-loop pattern 153 when oscillator 48 is also properly adjusted is shown in Fig. 6. The boundary of the screen is represented by the circles 150 and 151.

Referring now to Fig. 3, the transmitted band of television signals and the pilot frequencies received from the coaxial cable system 16 are impressed on a pilot suppression network 70 which suppresses all three of the pilot frequencies to a degree necessary to prevent troublesome distortions in the received picture. The remaining television signals are passed through a phase equalizer and band elimination filter 71, an amplifier 72 and a restorer network 73 before being impressed on the modulating input circuit of a balanced demodulator 74. The carrier frequency for this demodulator is furnished by oscillator 75 which is adjusted to supply a carrier frequency of 8256 kc.

The important frequencies appearing in the output circuit of demodulator 74 are an upper and lower side band and the modulating band. The demodulator 74 is arranged to suppress the carrier frequency. The lower side band extends downward from about 8056 kc. to 5144 kc. The upper side band extends from about 8456 kc. to 11,368 kc.

The frequencies in the output circuit of demodulator 74 are impressed on a band-pass filter 76. This filter 76 passes the lower side band from demodulator 74 and suppresses the rest of the frequencies in its output circuit.

This lower side band passed by band-pass filter 76 is impressed on a linear rectifier 77, the output circuit of which is connected through a low-pass filter 78 and video signal amplifier 79 to a cathode ray image producer 20. By means of a branch connection 80 the detected video signals

may be transmitted through connection 35 to the alternative circuits extending to building D.

Since linear detection with transmitted carrier is employed it is only necessary that the carrier frequency for demodulator 74 have a frequency reasonably close to the second carrier frequency produced by oscillator 51. Oscillators 51 and 75 are, therefore, adjusted independently by comparison with the 2064 kc. pilots at the terminals of the coaxial cable system. In determining the proper adjustment of oscillator 75, current of 2064 kc. from pilot frequency source 81 is impressed on the modulating input circuit of demodulator 74 through circuit 82 and a connection between terminals 83 and 84. For this purpose the connection to the coaxial cable system from terminals 84 to 85 is removed. Another way to supply the 2064 kc. pilot to the input circuit of demodulator 74 is to render ineffective the 2064 kc. pilot suppression apparatus. Of course no television signals should be incoming from the coaxial cable system during adjustment in this manner. Telephone receiver 86 which may be connected in the common lead of the balanced output circuit of demodulator 74, is used to give an audible indication while making the adjustment as will be described hereinafter.

The details of the circuit arrangements of demodulator 74 and oscillator 75 are shown in Fig. 4. The circuit from the terminal 84 to demodulator 74 is a section of concentric conductor 90 and the circuit between demodulator 74 and band-pass filter 76 is also a section of concentric conductor 91. The input network of demodulator 74 consists of a transformer 92, inductance coils 93 and 94, resistances 95 and 96 and condensers 97 and 98. This demodulator is of the balanced type comprising a pair of pentode vacuum tubes 99 and 100. The television signals are applied to the control grids of the two tubes in series and the carrier frequency from the oscillator 75 is applied to the same control grids in parallel. The 8256 kc. carrier frequency is applied through transformer 101, the windings of which are shunted by condensers 102 and 103, respectively. The parallel network consisting of resistance 104 and condenser 105 are connected in series with the secondary winding of transformer 101. The demodulator tubes 99 and 100 work into transformer 106 which has an impedance ratio of 1300 to 72 ohms and a pass band of 4900 kc. to 8100 kc. This transformer 106 has an impedance of 72 ohms when measured on the low side when each half of the high side is terminated in 650 ohms shunted by a 24 mmf. (micro-microfarad) condenser. The two halves of the high winding of transformer 106 are shunted by resistances 107 and 108, respectively. The center point of transformer 106 is connected to ground through condenser 109 and resistance 110. A pair of normally closed jacks 111 and 112 are connected in series with each other and in shunt of resistance 110 so that the resistance 110 is normally short-circuited. During adjustment of the frequency of oscillator 75 telephone receiver 86 is bridged across resistance 110 through jacks 111 and 112.

This demodulator 74 is very accurately balanced to suppress the 8256 kc. carrier frequency which otherwise would cause an interfering component in the detected video signals produced by the linear rectifier 77 due to modulation with the transmitted first carrier of 7944.727 kc. This accurate balance is obtained in the screen and the plate circuits of demodulator 74. The screen potentials for demodulator 74 are supplied by a direct current source represented by battery 115 through a combination of three potentiometers and two resistances. Resistances 113 and 114, each of 45,000 ohms, limit the maximum and minimum potentials which can be applied to the screens. Potentiometer 116 of 30,000 ohms is used as a rough carrier amplitude balance control. The potentiometers 117 and 118 each of 500 ohms maximum which are connected to the same control shaft and arranged to operate in opposition, serve as a fine amplitude balance control. The phase control is effected by a condenser 119 bridged across the terminals of transformer 106. Condenser 119 really consists of two condensers, one of which subtracts capacity from one plate circuit as it adds it 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. The total capacity range of each side of this condenser is about 3 to 10 mmf. A cam and lever arrangement attached to the condenser comprise a fine phase balance control. By proper adjustment of the phase and amplitude controls a carrier balance of the order of 75 db. down on the signal can be obtained. It has been found that although this balance may drift, it will always be better than 65 db. Since the balance requirement for this carrier leak is about 50 db., the actual balance which can be maintained is more than sufficient for all needs.

The oscillator 75 comprises a pentode oscillator tube 120 and a pentode amplifier tube 121 with the indicated associated circuit elements.

The procedure for adjusting the oscillator 75 to produce a frequency of 8256 kc. will now be described. The 2064 kc. pilot frequency is impressed on the modulating input circuit of demodulator 74 through transformer 92 in place of the television signals received from the coaxial cable system by way of terminal 85. Telephone receiver 86 is bridged across resistance 110 through jacks 111 and 112. Therefore, voltages developed across resistances 110 are impressed on the telephone receiver 86. Since all balanced demodulation products are present in the mid-branch circuit of the demodulator, that is, in resistance 110 which forms a series portion of the mid-branch circuit, they also are present in the telephone receiver 86. Consequently, when the 2064 kc. pilot frequency is impressed on the demodulator, the fifth order modulation product will be balanced and appear in the telephone receiver 86. Such fifth order modulation product is represented by the equation

$$f_T = f_{c_3} - 4 \times 2064 \text{ kc.} \qquad (18)$$

where f_T is the frequency of the tone heard in the telephone receiver 86 and f_{c3} is the frequency produced by oscillator 75. The carrier frequency f_{c3} is then varied until a zero beat is produced in the receiver 86. When this condition obtains the frequency of the oscillator 75 is 8256 kc. providing the actual pilot frequency has its normal value of 2064 kc.

Modulation requirements

The modulation requirements for the hereinbefore described specific system will now be set forth. Single frequency interference threshold data is given in Fig. 7. These curves represent a cross-plot of data obtained by experiment with cathode ray tubes of the type described in the paper by M. E. Strieby, identified hereinbefore,

and interpreted for the R. M. A. Standard television signal. These experiments determined the threshold of visibility for numerous horizontal and bar patterns and all results were expressed in terms of the relative brightness of the pattern and background. For a background brightness of from 0.1 to 0.5 foot lambert which is the minimum expected under television viewing conditions, the value of

$$\frac{\Delta B}{B}$$

for threshold of visibility has been found to be approximately a constant for any particular bar pattern. Curve H is for a horizontal bar pattern moving at the rate of one bar per second. Curve V is for a vertical bar pattern moving at the same rate. It is convenient to express this threshold of visibility requirement in terms of the maximum brightness of the picture. In the present system it is proposed to employ a reproducing tube which will have an effective linear range of 30 db. Then the

$$\frac{\Delta B}{B_{max.}}$$

requirement will be given by

$$\frac{\Delta B}{B_{max.}}=\frac{\Delta B}{B}+30 \text{ db.}$$

Now the R. M. A. signal has a peak to peak amplitude 2.5 db. greater than the peak to peak picture amplitude, the synchronizing pulses occupying this remaining portion of the composite signal. Then the threshold of visibility for any signal frequency bar pattern in terms of the peak to peak amplitude of the R. M. A. signal is given by

$$\frac{\Delta B}{B_{RMA}}=\frac{\Delta B}{B}+30+2.5=\frac{\Delta B}{B}+32.5 \text{ db.}$$

where

$$\frac{\Delta B}{B}$$

observed threshold of visibility.

Fig. 7 represents the single frequency interference threshold of visibility for a condition of a slowly moving pattern. This slow movement imposes a slightly more severe requirement than if the pattern were stationary. The observer is assumed to be viewing an 8" x 10" field at a distance of from 3 feet to 6 feet.

As pointed out previously, a necessary condition for low distortion, when envelope detection is employed, is the transmission of the carrier at a relatively high level with respect to the signal. This is accomplished by unbalancing the first modulator until the peak to peak amplitude of this transmitted carrier at the input terminals of the linear rectifier is 6 db. greater than the peak to peak amplitude of the modulating video signal. Since the transmitted R. M. A. signal does not contain direct current, this transmitted carrier has a constant average value.

For convenience the value of the unmodulated carrier will be used as a reference for expressing all interference requirements. Then the single frequency interference requirement at the input terminals of the linear rectifier will be those given on Fig. 7 increased by 6 db.

Since both transmitting and receiving terminals contribute equally to the vestigial shaping, a receiving terminal discriminates against the carrier by 3 db. more than at frequencies 100 kc. or more removed from the carrier. The requirement is thus increased by 3 db. at all points preceding the receiving terminal band filter where this semi-vestigial shaping is introduced.

Then, to summarize, the requirement on single tone interference introduced at the line position is 9 db. more severe than indicated by Fig. 7. For example, the requirement on a tone of 700 kc. introduced on the line, which would produce a received interference of 700—311=389 kc. approximately, would be 83.5 db below the value of unmodulated carrier at that point on the line.

Second and third order modulation of the carrier frequency

Second and third order modulation requirements of the transmitted carried, f_0, may be derived on a single frequency interference basis.

As hereinbefore pointed out, the present allocation affords a reduced requirement of 23.5 db. to be used for the second harmonic of the carrier frequency. This is due to the fact that the second harmonic of the carrier frequency which will occur at 622.546 kc., will fall approximately midway between the components of the line scanning frequency. Then referring to Fig. 7 the requirement on $2f_0$, which produces a received interference tone of 311.273 kc., will be

$$\frac{2f_o}{f_o}=74.5+9-23.5=\frac{1}{\nabla}60 \text{ db.}$$

The third harmonic of f_0 will produce a received interference pattern which will not have the benefit of being an $(n+\frac{1}{2})$ multiple of the line scanning frequency and the requirement may be written as

$$\frac{3f_o}{f_o}=74.5+9=\frac{1}{\nabla}83.5 \text{ db.}$$

where the received interference tone will be 622 kc. approximately.

The above coaxial cable basic requirements exist for a system which employs no predistortion. The subject of predistortion and a description of the final predistortion characteristic will be discussed hereinafter.

Pilot frequency modulation products

As hereinbefore explained, three pilot frequencies are employed for cable regulation purposes. These are 64 kc., 2064 kc., and 3096 kc. Various second and third order modulation products formed by combinations of these and the transmitted carrier will interfere with the received picture. Modulation requirements are derived from single frequency interference data on Fig. 7. A table of interfering products, and the requirements in terms of f_0, for a system employing no predistortion follows:

$$f_{p_2}\pm f_{p_1}=\frac{1}{\nabla}73.5 \text{ db.}$$

$$f_{p_3}\pm f_{p}=\frac{1}{\nabla}65.5 \text{ db.}$$

$$f_{p_3}\pm f_{p_2}=\frac{1}{\nabla}83.5 \text{ db.}$$

$$f_{p_1}\pm 2f_o=\frac{1}{\nabla}83.5 \text{ db.}$$

$$f_{p_2}\pm 2f_o=\frac{1}{\nabla}79.5 \text{ db.}$$

$$f_{p_3}\pm 2f_o=\frac{1}{\nabla}68.5 \text{ db.}$$

$$f_{p_1}\pm f_o=\frac{1}{\nabla}78.5 \text{ db.}$$

$$f_{p_2}\pm f_o=\frac{1}{\nabla}76.5 \text{ db.}$$

$$f_{p_3}\pm f_o=\frac{1}{\nabla}65.5 \text{ db.}$$

In the above, where upper and lower sideband products have different requirements, the most severe case is listed. It is to be noted that the above requirements hold for each product interfering alone. The increased requirement due to the addition of a number of simultaneous interfering products will not be considered at present. When the received interference tone from a modulation product is a $(n+\frac{1}{2})$ multiple of the line scanning frequency, a reduced threshold requirement may be used.

In the specific television system hereinbefore described the video band and the lower side band resulting from the first modulation do not overlap. If a balanced modulator is used for the first modulation which is carefully balanced to suppress the video band the first carrier may be chosen so that the lower side band overlaps the video band. In such a system lower carrier frequencies may be used but they should be chosen in accordance with the teachings of this invention to effect improvement in the transmitted television signals.

What is claimed is:

1. An electro-optical image producing system comprising a source of image signals having energy concentrations at harmonics of the line scanning frequency, and means to shift the frequencies of said image signals by multiple modulation to a frequency range partially overlapping the frequency range occupied by said original image signals, said means comprising sources of first and other carrier frequencies such that a harmonic of the shifted frequency corresponding to said first carrier frequency lies between adjacent energy concentrations in said shifted range.

2. A television system comprising means to produce television signals occupying a wide band of frequencies and having energy concentrations at harmonics of the frequency corresponding to the line scanning frequency, a transmission circuit adapted to transmit said television signals, and means comprising a source of pilot current of frequency included within said wide band of frequencies but intermediate to adjacent harmonics of said frequency corresponding to the line scanning frequency and a control means to control a transmission characteristic of said circuit by pilot current from said source.

3. A television system of the kind in which the video signals are transmitted as modulations of a carrier current and a component of unmodulated carrier current is transmitted therewith to effect detection at the receiver comprising means to produce a video signal having a line scanning frequency of selected value, means to produce transmission current having frequency components corresponding to the respective frequency components of said video signal moved upward in the frequency spectrum by a constant amount including a source of carrier frequency and means to modulate said carrier frequency by said video signals, the frequencies being so chosen that a selected harmonic of the component of the transmission current corresponding to said carrier frequency lies intermediate the two frequencies in said transmission current corresponding to two adjacent harmonics of said line scanning frequency, and means to transmit said transmission current.

4. A system for transmitting television signals over a transmission circuit comprising a large number of amplifiers in tandem, means for producing a video signal having energy concentrations at integral multiples of the line scanning frequency, means for shifting the video signal band by modulating a first carrier current of such frequency that the essential lower side band lies wholly above the essential video band, means for selecting and transmitting said lower side band and an amount of unmodulated first carrier current at least equal to the peak to peak amplitude of the selected side band, means for shifting the selected and transmitted band including the component of unmodulated first carrier current by additional modulation to a frequency range which includes a harmonic of the shifted frequency corresponding to the first carrier current frequency and wherein said harmonic lies in the central portion of the frequency space between two adjacent shifted energy concentrations, and means for amplifying said last shifted band in said transmission circuit amplifiers at a current level which produces an amount of said harmonic of the shifted frequency corresponding to the first carrier current which would cause distortion greater than is permissible under predetermined tolerances in an image produced from said amplified shifted band if said harmonic of the shifted frequency corresponding to the first carrier current frequency coincided with a shifted energy concentration.

5. A system for transmitting television signals over a transmission circuit comprising a large number of amplifiers in tandem, means for producing a video signal having energy concentrations at integral multiples of the line scanning frequency, means for shifting the video signal band by modulating a first carrier current of such frequency that the essential lower side band occupies a frequency range displaced with respect to the essential video band, means for selecting and transmitting said lower side band and an amount of unmodulated first carrier current at least equal to the peak to peak amplitude of the selected side band, means for shifting the selected and transmitted band, including the component of unmodulated first carrier current, by additional modulation to a frequency range which includes a harmonic of the shifted frequency corresponding to the first carrier current frequency and wherein said harmonic lies in the central portion of the frequency space between two adjacent shifted energy concentrations, and means for amplifying said last shifted band in said transmission circuit amplifiers at a current level which produces an amount of said harmonic of the shifted frequency corresponding to the first carrier current which would cause distortion greater than is permissible under predetermined tolerances in an image produced from said amplified shifted band if said harmonic of the shifted frequency corresponding to the first carrier current frequency coincided with a shifted energy concentration.

6. A television system comprising means to produce video signals of the R. M. A. type having energy concentrations at the line scanning frequency of substantially 13.23 kc. and harmonics thereof, a first modulator adapted to transmit a controlled amount of unmodulated carrier current along with the side bands produced therein, means to impress said video signals on the modulating input circuit of said first modulator, a first source of carrier current of a frequency substantially equal to 7944.727 kc. adapted to supply carrier current to said first modulator, a band-pass filter connected to the output circuit of said first modulator having a

lower cut-off at approximately 4900 kc. and an upper cut-off at approximately 8056 kc., a second modulator of the balanced type adapted to suppress the carrier current and transmit the side bands having a modulating input circuit connected to the output circuit of said band-pass filter, a second source of carrier current of a frequency substantially equal to 8256 kc. adapted to supply carrier current to said second modulator, a low-pass filter having an upper cut-off at approximately 3300 kc. connected to the output of said second modulator, and means to utilize the television signals passed by said low-pass filter.

7. In a signaling system, a modulator, a source of carrier current for said modulator, a transmission circuit, a source of pilot frequency associated with said transmission circuit for controlling a transmission characteristic thereof, and means to adjust the frequency of the carrier current supplied by said source of carrier current and indicate when the frequency bears a predetermined relationship to the frequency of said pilot frequency.

8. In a television system, a modulator, a source of carrier current for said modulator the frequency of which is adjustable, a coaxial cable system having a plurality of amplifiers connected in tandem, a source of pilot frequency of 2064 kc. associated with said cable system for regulating the gain in said amplifiers, means for indicating the proper frequency adjustment of said source of carrier frequency comprising a cathode ray oscilloscope having coordinate deflecting means, means to impress a second harmonic of said pilot frequency on one deflecting circuit, and means to impress carrier current from said source of carrier current on said other deflecting circuit, and means to vary the frequency of said source of carrier current to produce a stationary double loop pattern on the screen of said oscilloscope along the axis corresponding to said second harmonic of said pilot frequency.

9. In a television system, a first and second modulator each having modulating input circuits and output circuits, a coaxial cable system having a plurality of amplifiers connected in tandem, means to produce two pilot frequencies of 64 kc. and 2064 kc., respectively, associated with said cable system for regulating the gain of said amplifiers, means to impress a carrier current of 8256 kc. on said second modulator, means to impress said 64 kc. pilot frequency on the modulating input circuit of said first modulator, a source of carrier current for said first modulator, means to select the lower side band from said first modulator and impress it upon the modulating input circuit of said second modulator, means to select a lower side-band frequency from the output of said second modulator corresponding to the lower side-band frequency from said first modulator resulting from the 64 kc. pilot frequency impressed on the modulating input circuit of said first modulator, means for indicating the proper frequency adjustment of said source of carrier frequency for said first modulator comprising a cathode ray oscilloscope having coordinate deflecting means, means to impress the second harmonic of said 2064 kc. pilot frequency on one said deflecting circuit, means to impress said selected sideband frequency from the output of said second modulator on said other deflecting circuit, and means to vary the frequency of said source of carrier frequency for said first modulator to produce a stationary eleven-loop pattern on the screen of said oscilloscope along the axis corresponding to said selected side-band frequency.

10. In a television system, a balanced demodulator adapted to suppress the carrier current impressed thereon having a modulating input circuit, an output circuit for the side bands and a common circuit in which the fifth order modulation product is present, a source of carrier current for said demodulator the frequency of which is adjustable, a coaxial cable system having a plurality of amplifiers connected in tandem, means to produce a pilot frequency of 2064 kc. associated with said cable for regulating the gain of said amplifiers, means for indicating the proper frequency adjustment of said source of carrier frequency comprising a resistance connected in series in said common circuit, a telephone receiver connected in shunt across said resistance, and means to impress said 2064 kc. pilot frequency on the modulating input circuit of said demodulator, and means to adjust the frequency of said carrier current to cause a zero beat in said telephone receiver.

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