

Dec. 29, 1942.

R. E. GRAHAM

2,306,435

FREQUENCY COMPRESSION

Filed Jan. 17, 1941

7 Sheets-Sheet 2

FIG. 2a

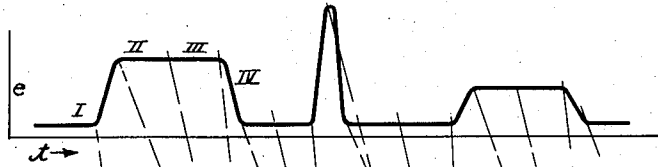
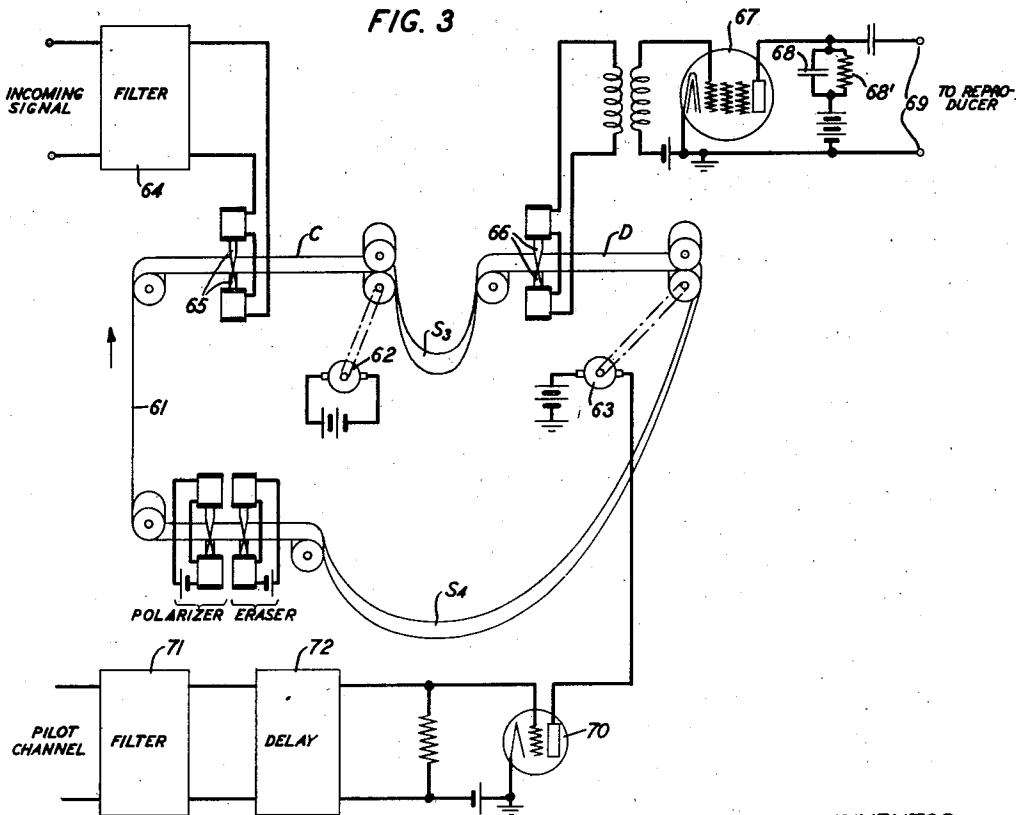


FIG. 2b



FIG. 3



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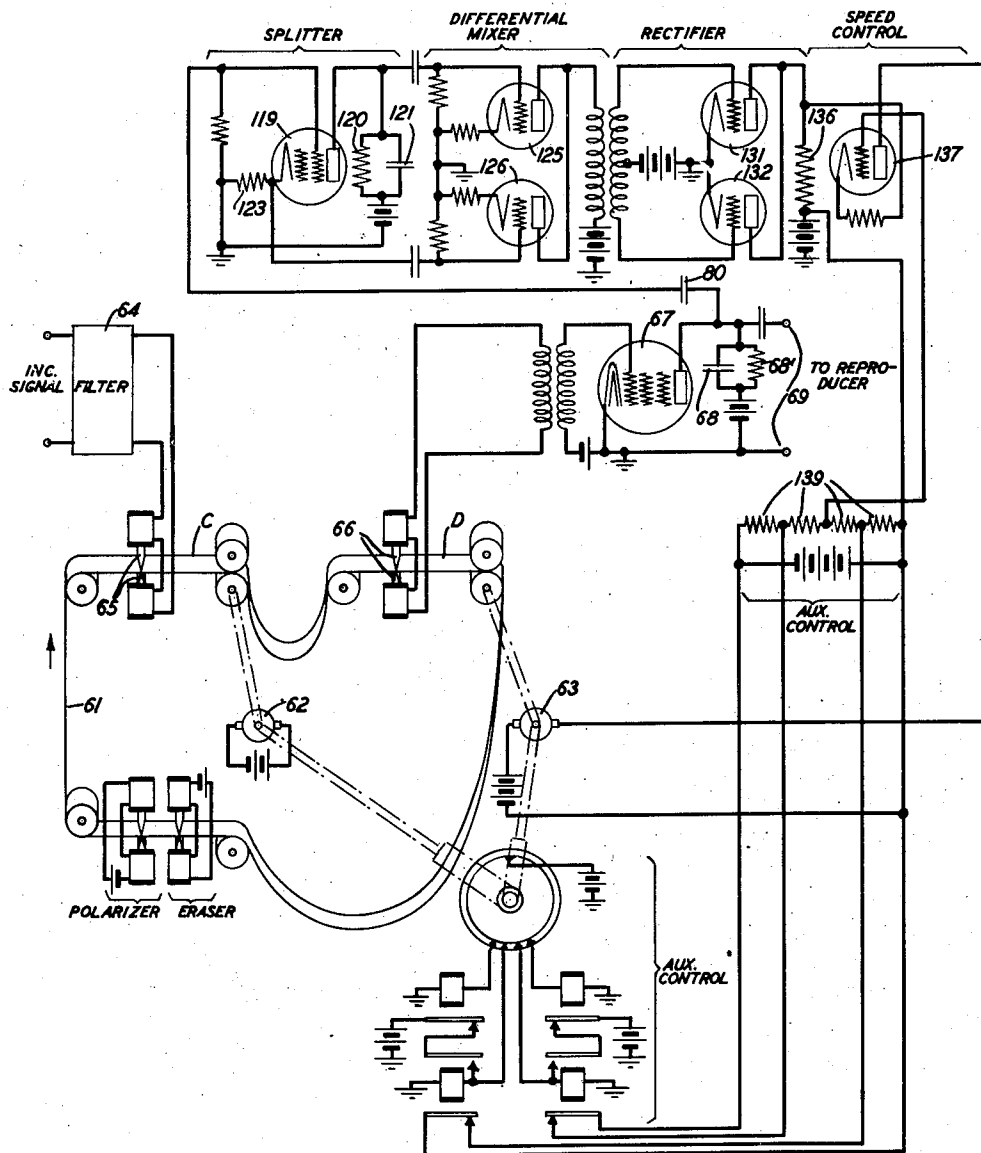
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FREQUENCY COMPRESSION

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-7 Sheets-Sheet 3

FIG. 4



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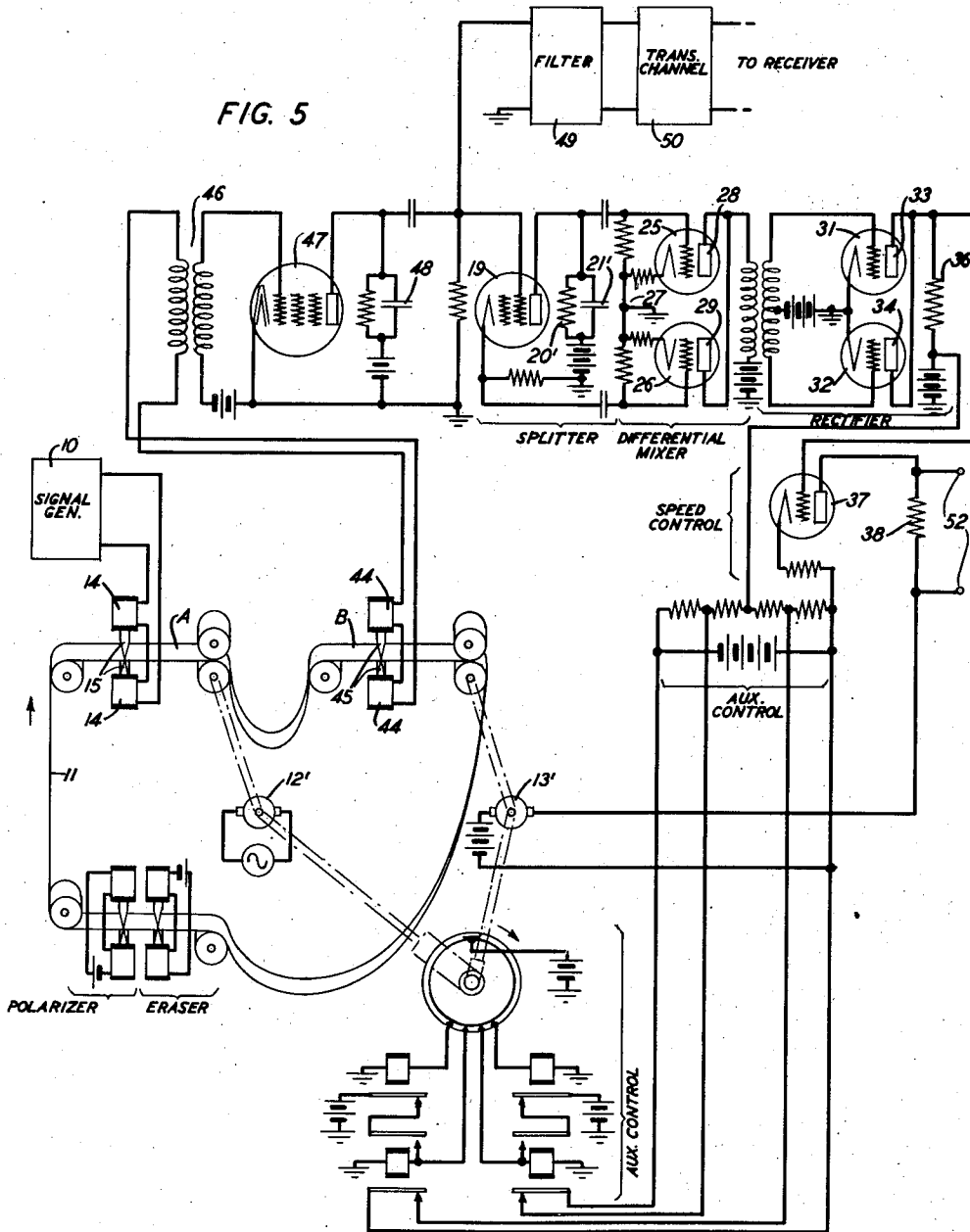
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FREQUENCY COMPRESSION

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7 Sheets-Sheet 4



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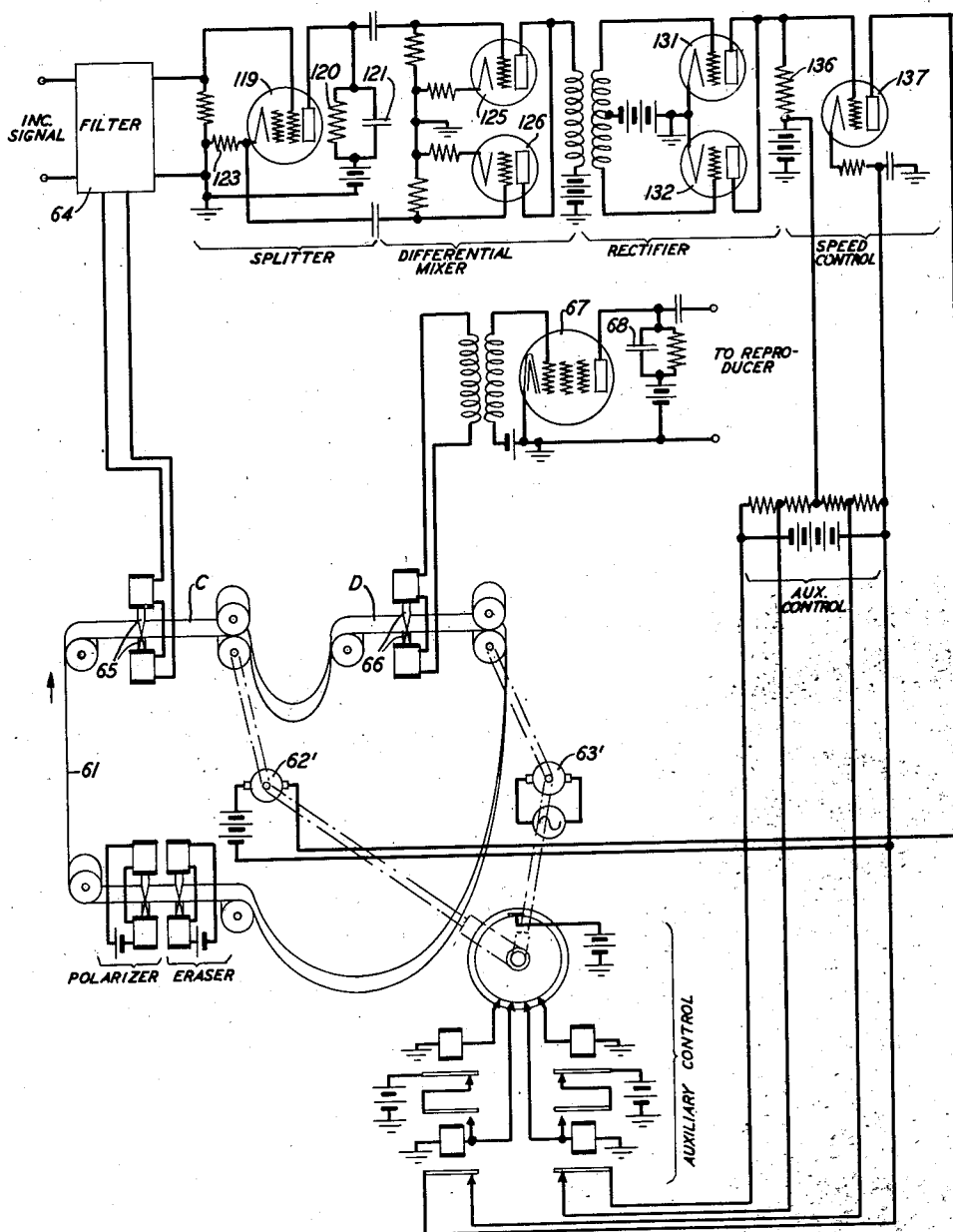
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FREQUENCY COMPRESSION

2,306,435

Filed Jan. 17, 1941

7 Sheets-Sheet 5

FIG. 6



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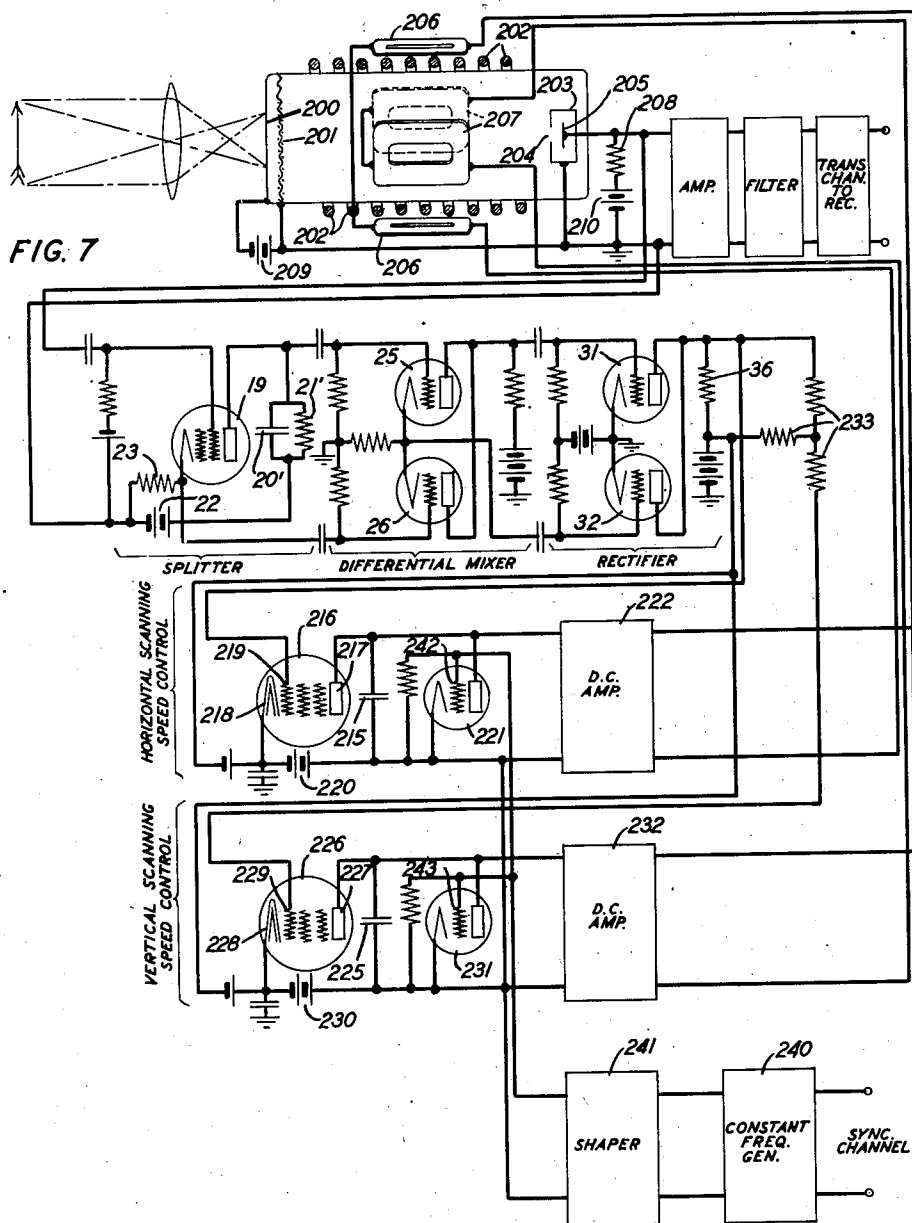
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FREQUENCY COMPRESSION

Filed Jan. 17, 1941

7 Sheets-Sheet 6



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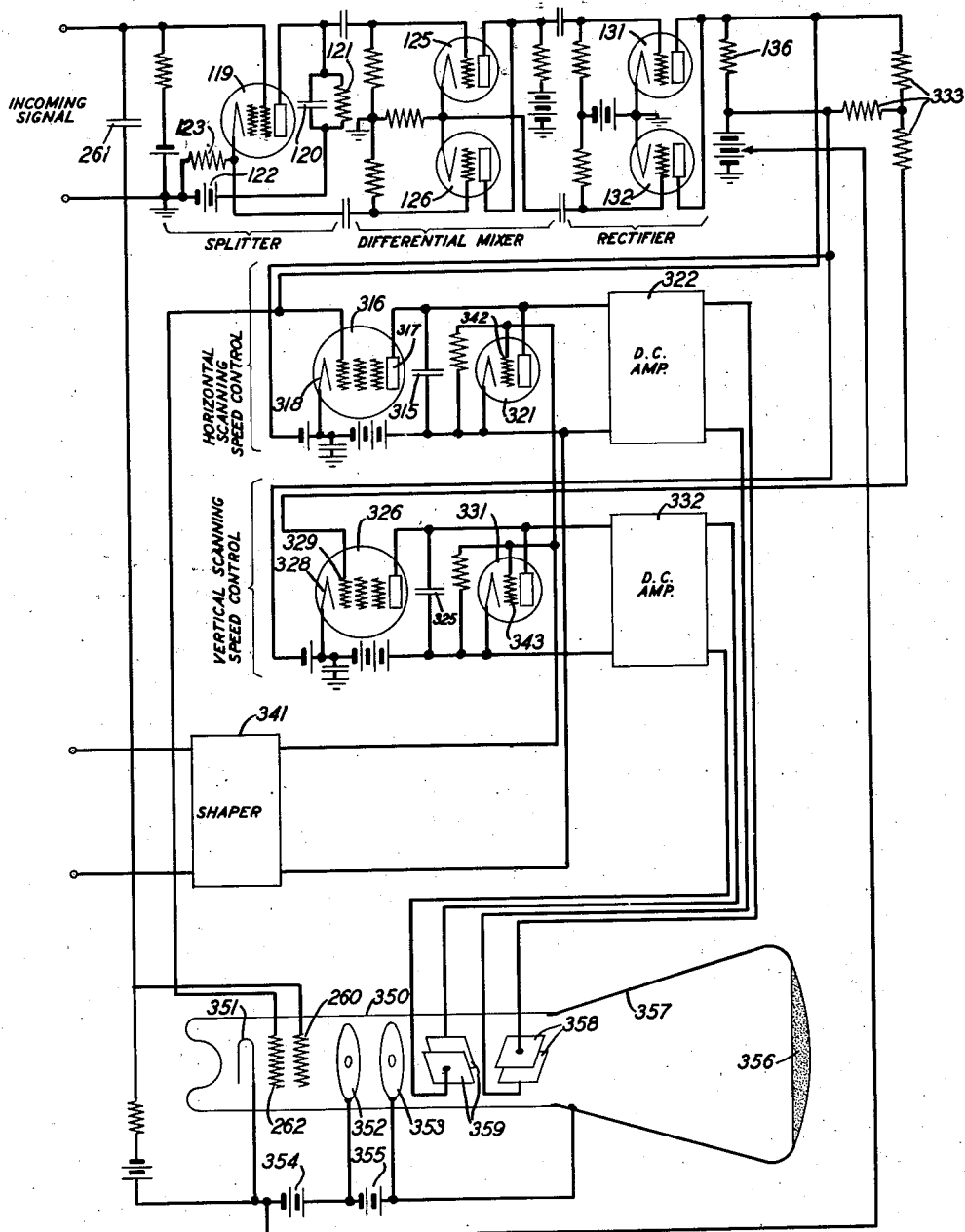
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FREQUENCY COMPRESSION

Filed Jan. 17, 1941

7 Sheets-Sheet 7

FIG. 8



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UNITED STATES PATENT OFFICE

2,306,435

FREQUENCY COMPRESSION

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Application January 17, 1941, Serial No. 374,860

27 Claims. (Cl. 178—6.8)

This invention relates to the translation, transmission, reception and reproduction of electric communication signals, particularly television image signals and the like.

A principal object of the invention is to effect a substantial reduction in the width of the frequency band required for the transmission of such signals as compared with the band width required when the transmission is effected by the apparatus and in accordance with the methods commonly in use.

Other objects are to provide apparatus and methods for accomplishing this principal object.

Still other objects will be apparent from the following description.

It is a feature of communicable information and therefore of the electric signals employed in the communication art to carry such information from place to place, that their information contents vary from time to time. In the case of television or other image signals, for example the rapidity of fluctuation which measures the information content may and frequently does vary between comparatively wide limits in a short time, corresponding to the variation of detail in the field of view from point to point of this field.

Associated with this variation of the rapidity of the fluctuation of the signals there is a corresponding variation in the frequency band width required to transmit signals without excessive distortion. If the condition did not exist, it would be possible to assign each message to a channel which would be suited to it in that the signal could pass through the channel without objectional distortion while the available frequency space or band width would be fully utilized at all times; that is, to each message a channel could be allocated which should be wide enough to carry the message without serious distortion and no wider. But because the character of the signals changes between such wide limits over relatively short periods, channel demands, measured by the rapidity of fluctuation of the signal, are comparatively low at some times and at others comparatively high. In the case of television signals for example, this variation may be from a value of the order of the line scanning frequency to another value of the order of the picture element frequency and may take place within the short time required to scan a single line. Scanning, amplifying, transmitting and receiving apparatus must be designed to satisfy certain standards of quality under the most demanding of these conditions, and in consequence a signal channel must be provided whose frequency pass-

band is wide enough to transmit without excessive distortion those portions of the signals whose rapidity of fluctuation is greatest. This means that at all times except when the rapidity of fluctuation is greatest, a large part of the available frequency band width lies idle. Evidently this places severe requirements on the communication system and at the same time constitutes an inefficient use of it, adding to the cost of the apparatus and reducing the number of messages that can be transmitted within a given time.

It has already been proposed, in order to reduce the channel width required to transmit a television signal, to modify or predistort it prior to transmission in accordance with and under control of the time rate of change of the signal itself. As will readily be understood by those skilled in the art, the time rate of change or first derivative of the signal is insufficient as a control because a system employing it inevitably fails to discriminate between signals which are widely different in many respects but nevertheless alike in their first derivatives. This may readily be seen for a simple case by comparing two signals of like wave form, the one being of twice the frequency and one-half the amplitude of the other. Their slopes or first derivatives are alike, and a system depending on first derivative control will necessarily fail to distinguish between them.

In accordance with the invention and in furtherance of its broad object, the limitations of the usual systems and the objections to systems hitherto proposed, as improvements thereover, may be avoided in the following way. The signal to be transmitted is first modified in such a way that while the modified signal still contains all the convolutions of the original signals, the rapid fluctuations are reduced in rapidity and the slower fluctuations increased in rapidity to such a point that the modified signal is more nearly uniform from the standpoint of rapidity of the fluctuation or channel band width requirements than was the original signal. This modified signal may now be transmitted over a channel which may be of greatly reduced width. At the receiver, the modified signal may be restored to its original form for utilization or reproduction by a complementary operation. The necessary control information as to the nature and extent of the modification may be transmitted to the receiver either separately from the main signal over a pilot channel as explicit information, or it may be contained implicitly in the modified signal itself. In either case the terminal apparatus may be constructed and adjusted to respond to this control

information to produce the complementary modification.

Thus in one aspect the invention comprises a system for compressing the frequency band width, required for the signal at the transmitter, passing the compressed signals through a comparatively narrow channel and expanding the band width in complementary fashion at the receiver. In another aspect, it comprises apparatus for modifying the signal wave form in such a way as to render the rapidity of the fluctuation more nearly uniform over the message period while still retaining all of its information-carrying convolutions, and inverting the operation at the receiver.

In accordance with the invention, the modification of the signal may be effected as follows. The signal may be first recorded or stored in a suitable medium by recording apparatus traveling at a certain speed, for example, a speed which varies directly with the rapidity of fluctuation of the signal; and thereafter the modified signal may be recovered from the storage medium by pick-up apparatus traveling at a different speed, for example, a constant speed. Or, if preferred, the recording may be at constant speed and the recovery at a speed which varies inversely with the rapidity of fluctuation. In television or picture transmission embodiments the recording step may conveniently comprise the projection of an optical image of a field of view on a suitable photosensitive surface and the modified signals may then be obtained merely by scanning the surface at a speed varied in accordance with the rapidity of fluctuation of brightness of the image with distance measured along the surface.

In each case the variable velocity control may be secured in accordance with the invention by means of a novel circuit arrangement whose operation is such that when a suitable signal is applied to its input terminals a signal appears at the output terminals which is a function of the first and higher order time derivatives of the original signal and is a measure of the distortion which would be introduced into the unmodified signal if the latter were sent over the transmission channel of reduced width without modification. In one embodiment the input signal to this circuit arrangement is the original signal, unmodified. In another embodiment the input signal is a partially modified version of the original signal, the modification being secured by repeated passages around a closed feedback loop of which the difference-taking circuit arrangement forms a part.

In one embodiment this output signal is equal to the difference between the unmodified signal and the same signal as it would appear after transmission over the distorting channel. For the sake of illustration this channel may be regarded as a transmission line having a stipulated frequency characteristic, for example, a cut-off frequency such that high frequency components of the unmodified signal would be severely attenuated. When the original signal has a high rapidity of fluctuation, corresponding to a large information content, the distortion due to the line would be great and the difference signal is large. Under opposite conditions it is small. It is supplied to a motor or other device which drives either scanning or recovery apparatus in such a way as to increase or reduce its speed respectively when the channel demand is high, and alter it in the opposite sense when the demand is low.

It is a feature of the invention that the control

exerted to modify the original signal is a function, not alone of its time rate of change, but of its first and higher order time derivatives.

Further understanding of the central inventive thought may be gained from a mathematical analysis of the mode of operation of the apparatus and of its modifying action on the signal, which analysis supplements the above general description.

An original signal $e(t)$, characterized by a wave form having relatively rapid fluctuations in some portions and relatively slow fluctuations in other portions is to be operated upon in such a way as to expand its time scale and so spread out its convolutions over the rapidly fluctuating portions and contract its time scale and so compress its convolutions over the more slowly fluctuating portions. Corresponding to a differential time interval dt for the original signal there will be, in general, a modified interval ρdt for the modified signal, where the quantity ρ , a "smoothing factor," is less than unity for an expanded interval and is greater than unity for a compressed interval. Then, corresponding to a time t in the original scale built up of differentials dt , the new scale will be built up of differentials ρdt , and corresponding to the original signal

$$e(t) = e\left(\int_0^t dt\right)$$

the modified signal will be given by

$$e_1(t) = e\left(\int_0^t \rho dt\right) \quad (1)$$

Evidently, the modified signal

$$e\left(\int_0^t \rho dt\right)$$

will endure longer, that is, it will require a longer interval in t , true time, to describe a given number of convolutions, for $\rho < 1$, than the original signal $e(t)$; while for $\rho > 1$ the reverse is the case. Thus by a judicious varying of the "smoothing factor ρ ," the sharper transitions of the original signal may be smoothed out and the slow transitions speeded up. At the same time for every convolution of $e(t)$ there is still a corresponding and generally different though related convolution of $e_1(t)$.

The signal may now be transmitted in the modified form

$$e\left(\int_0^t \rho dt\right)$$

over a comparatively narrow band transmission channel to a receiver station where it may be restored to the original form $e(t)$ by an inverse operation; i. e., by applying compression to the expanded portions of the time axis and vice versa.

It is desirable that an arbitrary portion of the modified signal, for example in the case of television, a full frame shall occupy the same time as the corresponding portion of the original signal or, in other words, that the modified signal shall have the same average transmission speed as the unmodified signal would have had. This is in order that transmission and reception may be substantially contemporaneous. This condition is mathematically expressed by the statement

$$\int_{t_a}^{t_b} (1 - \rho) dt = 0 \quad (2)$$

where the time interval t_a to t_b is the one over which the transmission speed is averaged. For

practical applications it will be sufficient to use the criteria

$$\left| \int_0^t (1-\rho) dt \right| < \delta \quad (3)$$

which states that the absolute value of the integral on the left-hand side of the equation never exceeds a certain limiting value given by δ , a small number, indicating the permissible departure of the practical system from ideal behaviour. The longer the time interval $0-t$ taken, the less, in general, will be the departure from zero of the magnitude of the integral.

With the above in mind, and referring to a physical embodiment in which the original signal is recorded on a storage medium at one speed v_1 and the modified signal recovered therefrom at another speed v_2 , it will be recognized that the speed ratio

$$\frac{v_2}{v_1}$$

may be made to serve for the quantity ρ in the above expressions, and that the function of the auxiliary control apparatus above referred to is to apply a brief corrective influence at times when the integrated speed ratios are such as to violate the condition 3.

In accordance with the invention there is further provided auxiliary control apparatus of the type sometimes referred to as "follow up" apparatus to prevent the recovery device or pick-up from overtaking the recording apparatus or lagging too far behind it. This auxiliary control apparatus impedes the operation of the main portion of the apparatus whenever excessive lag or overtaking is about to occur and restores the lag to an average value.

The invention will be fully understood from the following detailed description of certain illustrative embodiments thereof taken in connection with the appended drawings, in which:

Fig. 1 is a diagram of transmitter apparatus in accordance with the invention;

Fig. 2a shows a part of the wave form of an unmodified signal;

Fig. 2b shows a corresponding part of the wave form of the same signal after modification thereof by the apparatus of Fig. 1;

Fig. 3 shows receiver apparatus in accordance with the invention;

Fig. 4 shows an alternative arrangement of receiver apparatus;

Fig. 5 shows an alternative arrangement of transmitter apparatus;

Fig. 6 shows another alternative arrangement of receiver apparatus;

Fig. 7 shows transmitter apparatus particularly suitable for treatment of television signals in accordance with the invention; and

Fig. 8 shows receiver apparatus particularly suitable for reconstitution of television signals received after modification and transmission over a channel of reduced width in accordance with the invention.

Referring now to Fig. 1, a signal generator is indicated by a block 10. This may, for example, comprise apparatus for converting an optical image of a field of view into a complex electrical image signal as a function of time. Apparatus of this type is well-known in the art and need not be further described, although if detailed information as to the construction and operation of the various types of such apparatus is desired, reference may be made to "Television—The elec-

tronics of image transmission," by V. K. Zworykin and G. A. Morton. A part of an image signal delivered by this apparatus is represented in highly simplified form in Fig. 2a, in which voltage is plotted as a function of time for a small part of such a signal corresponding to the variation of brightness over a small portion of the field of view.

For reasons which will be apparent below, the internal connections of the generator 10 are preferably such that its output impedance is comparatively high.

A storage medium is provided, shown by way of example as a magnetizable tape 11 with associated recording and pick-up poles and windings. Storage systems of this kind, for a complete description of which reference may be made to the Bell System Technical Journal for April, 1937, at page 165, are well known per se and need not be further described. In accordance with the invention, different portions of the tape are arranged to be driven at different speeds, and to this end two separate motors are provided, each of which drives a roller which advances a particular part of the tape at a speed independent of the other. In the modification shown in Fig. 1 the portion A of the tape is driven by a motor 12 at varying speeds under control of apparatus later to be described, while the portion B is driven at constant speed by another motor 13. The latter may, for example, be a synchronous motor supplied with alternating current from a constant frequency source. The difference between the advance of the portion B and that of the portion A due to integrated speed differences may be accommodated by slack portions of the tape at two points S₁, S₂.

In order that the magnetizable tape may be an endless band and that all parts of it may be used repeatedly for storage and recovery of signals, it is preferred to provide means for erasing signals which have served their purpose and preparing the tape to receive other signals. Means of this character, which are well known per se, are fully described in the aforementioned article in the Bell System Technical Journal for April 1937 at page 165. Such means are generally indicated in Fig. 1 by auxiliary poles and windings energized by a direct current source, though any suitable arrangement for this purpose may equally well be employed.

The signal output of generator 10 divides into two paths. The first path leads to windings 14 of the recording poles 15 which are disposed to record the signal on the portion A of the tape. It is an order that the resulting space signal recorded on the tape shall be a replica of the original signal and not its time integral that the generator 10 is preferably a high impedance source. A constant time delay circuit 16 is preferably included in this path. It may be of a type well known per se and is symbolically indicated by a block 16.

The second path leads from the generator terminals to the input terminals of a novel circuit arrangement of the invention which will now be described. A high impedance discharge device, for example tube 19 having cathode, anode and a control electrode is provided. Connected in series between the anode and the cathode are an impedance element 20—21, a source of anode potential 22 and a resistor 23. The impedance element 20—21 should have an attenuation versus frequency characteristic which simulates that of the transmission line or other channel over which

the modified signals of the invention are to be transmitted, or at least have the same general trend. In the embodiment shown, this impedance element consists of a resistor 20 and a condenser 21 connected in parallel. As is well known, the impedance of such a parallel arrangement of a resistor and a condenser is governed by the resistor 20 at low frequencies and by the capacitor 21 at high frequencies. Its greatest value is for zero frequency and its value falls off continuously with increasing frequency. Its characteristic therefore resembles, more or less, that of a low-pass filter or an ordinary transmission line of a type now in common use. The values of resistance and capacitance should be so chosen that at frequencies near the lower end of the pass-band of the channel through which the signals are eventually transmitted, the impedance is substantially that of the resistance 20, whereas at frequencies within the pass-band but near its upper end the impedance is substantially the capacitive reactance of the condenser 21. The resistor 23 should be of the same resistance value as the resistor 20, and the internal resistance of the tube 19 should be high in comparison with both of these resistors in order that its anode current shall be substantially independent of the load impedance. The resistor 23 is grounded at its end remote from the cathode, and this point and the control electrode of the tube 19 constitute its input terminals whereas the anode and cathode constitute its output terminals. The output energy path leads from the anode and cathode of this tube through stopping condensers 24 to the control electrodes of two discharge devices 25, 26 of flat frequency response connected as a balanced input push-pull amplifier with the mid-point 27 of the input circuit grounded. Each of devices 25, 26 is preferably provided with a stabilizing resistor in its anode-cathode circuit to insure that its plate current-grid voltage characteristic shall be sensibly linear throughout the frequency range dealt with, and the control electrodes are returned through resistors to ground in the usual manner. The anodes 28, 29 of these discharge devices are not connected in push-pull, however, but are connected in parallel and supply energy through a coupling, for example, a transformer 30 to the input terminals of a balanced rectifier, for example the push-pull connected control electrodes of two matched discharge devices 31, 32 of flat frequency response whose anodes 33, 34 are connected in parallel. Each of the discharge devices 31, 32 is preferably biased to its plate current cut-off and for this purpose a biasing battery 35 is shown connected between the mid-point of the secondary winding of the input transformer 30 and the cathodes of the two discharge devices 31, 32 which are, in turn, grounded. Output energy from the balanced rectifier is impressed on a resistor 36 to provide input energy for a speed control circuit. The latter may comprise a three-electrode discharge tube 37 having cathode, anode and control electrode, the cathode being preferably connected to a resistor which provides control grid bias and improved stability. The control grid is returned to the mid-point of a tapped resistor 39 across whose terminals is connected a source of potential, for example, a battery 40. The end and intermediate points of this resistor 39 are connected to an auxiliary follow-up control device which will be described below.

Output current of this motor control circuit

may be supplied through load resistor 38 to the armature terminals of the motor 12 which drives the portion A of the tape 11. The motor 12 is preferably one whose speed varies easily and widely with variations in the current supplied to it.

Magnetic poles 45 and windings 44 are disposed along the portion B of the magnetic tape 11 to recover the signals stored in the tape in magnetic form and reconvert them to electric signals. The pick-up windings 44 are coupled through a transformer 46 to the cathode and control electrode of a discharge device 47 in whose anode circuit is connected an integrating impedance, for example, a condenser 48 shunted by a resistor 48'. The discharge device 47 is preferably a constant current device, and may be, for example, a five-electrode tube having a screen grid and suppressor grid in addition to the control grid as shown. To assist in realizing the full advantages of the invention the terminals of the impedance 48 are connected to a filter 49 which may be of any appropriate construction and may be designed to pass frequencies from zero to some upper limit which may be substantially lower than the upper limit which would be required if it were not for the advantages provided by this invention. The output terminals of this filter 49 constitute the ultimate signal output terminals of the transmitting apparatus as a whole, but in order that the operation of the apparatus may be better understood, they are shown as being connected to a low-pass transmission line or channel 50.

In order the better to understand the operation of the invention it will be helpful to designate various parts of the apparatus by functional designations. It so happens that the functional divisions in the apparatus as shown in Fig. 1 coincide in large measure with the structural divisions. It is to be understood, however, that the invention is equally applicable to an arrangement in which functional divisions overlap the structural divisions or vice versa; that is to say, to an arrangement in which one apparatus unit performs more than one function or a plurality of apparatus units cooperate to perform one function.

Since in the particular circuit arrangement shown, functional divisions coincide with apparatus divisions, such a designation becomes a relatively simple matter. Thus the apparatus in the upper left-hand corner of Fig. 1 starting with the input terminals of the discharge device 19 and running to the stopping condensers 24 may be termed a splitting circuit. The next apparatus unit in line, running from the stopping condensers 24 to the transformer 30 constitutes a differential mixing circuit. The third unit in the upper part of the figure, starting with the transformer 30 and running to the resistor 36 is a rectifier. The circuit arrangement in the right-hand portion of the figure, running from the resistor 36 to the output terminals of the discharge tube 37, constitutes a speed control circuit.

The operation of the apparatus of the invention is as follows. When a signal voltage of any particular wave form, for example the wave form of Fig. 2a, is impressed on the input terminals of the splitter circuit, two corresponding voltage drops appear across the cathode resistor 23 and the anode impedance 20-21, respectively. The voltage drop across the cathode resistor 23 is a replica, so far as wave form is concerned, of the input signal voltage, but the voltage drop across the anode impedance 20-21 may or may not be a

distorted version thereof, depending on whether the rapidity of fluctuation of the signal wave form is high or low. This voltage drop is broadly similar in wave form to that which would appear at the receiving end of the narrow band transmission channel 50 if the signal input thereto were not first modified in accordance with the invention, inasmuch as its sharper corners and transitions have been rounded off. These voltages across 23 and 20—21, which are of opposite polarity with respect to ground potential, are impressed on the differential mixer circuit. Since the output terminals of the latter are connected in parallel, it will be understood that with balanced voltages on the grids of the mixer tubes 28, 29 there will be no net signal current in the output circuit of the device, for example, the transformer 30, although the discharge current of each tube will vary as its own control grid potential swings due to the signal voltage impressed upon it. This condition will hold when the signal input to the splitter circuit is of such a character that the voltage drop across the anode impedance 20—21 has substantially the same wave form as that across the cathode resistor 23. This will be the case when the signals happen to be of such a low rapidity of fluctuation or information content that they would not be modified in wave form to any substantial extent by passage through the transmission line 50 and therefore are not substantially modified in wave form by passage through the impedance 20—21 whose frequency characteristic simulates or has the same general trend as that of the line 50. Such, for example, are the signal portions II, III of Fig. 2a. Under these conditions no energy will be transferred through the transformer 30 to the rectifier and therefore the motor control tube 37 delivers only its steady current to the variable speed motor 12 which in turn rotates at a certain preassigned speed which is less than the speed of the pick-up motor 13. Thus, in effect, the time base of the signal recorded on the magnetic tape is compressed as compared with the original signal, as indicated by the corresponding portions of Fig. 2b.

On the other hand, when the rapidity of fluctuation of the original signal wave form is so great that the transmission line 50 would, and therefore the impedance 20—21 in the splitter circuit will attenuate its higher frequency components, the voltage drops across the resistor 23 and the impedance 20—21 will differ from each other. This occurs when the signal is of the sort shown in portions I, IV of Fig. 2a. The impedance offered to such a signal by the network 20—21 differs considerably from that offered to it by the resistor 23. Therefore, the voltages impressed on the control grids of the two tubes 25, 26 of the differential mixer circuit will not be alike, and the average plate currents of these two tubes will be modified to a different extent. This current difference is proportional to the difference between the original unmodified signal and the signal as modified by operation of the impedance network 20—21. This difference signal is impressed through the transformer 30 on the input terminals of the tubes 31, 32 of the full wave rectifier. Since, as above stated, the tubes 31, 32 are biased to cut-off, a downward swing in the potential of the control grid of either tube does not affect the current in that tube, but an upward swing in the potential of the grid of either tube gives rise to a current through the resistor 36, to produce an increase

in the potential of the grid of the speed control tube 37. Thus, independent of the polarity of the output of the differential mixer, there results an increase in the current flow to the anode of the control tube 37 and therefore an increase in the current supplied to the tape-driving motor 12. Under these conditions, therefore, the speed of the portion A of the magnetic tape is increased in such a manner as to spread the convolutions of the signal recorded thereon by the recording poles further apart than they would otherwise be. This is in effect a spreading out or expansion of the time base of the signal recorded on the magnetic tape as compared with the time base of the original unmodified signal, as indicated in portions I, IV of Fig. 2b; and successive expansions and compressions produce a modified signal having a wave form as shown in Fig. 2b, in which no attempt has been made to preserve exact relationships, the diagram being merely indicative of the general character of the wave form of the modified signal.

The motor 12 and associated speed control circuits may be initially adjusted so that a stipulated average amount of rapidity of fluctuation in the signal gives rise to a motor speed the same as that of the pick-up motor 13. When the rapidity of fluctuation is less than this stipulated amount, as in the case first above described, the motor speed is reduced to compress the space signal. When the rapidity of fluctuation exceeds this stipulated amount as in the case last above described, the motor speed is increased resulting in an expansion in the space signal.

The mathematical theory underlying the operations performed by the apparatus described above may be of assistance in understanding them. In particular it clearly brings out the fact that the invention does not operate by mere first derivative control.

This theory is here given in terms of the illustrative example shown in the figure in which the signal-modifying circuit consists of a resistor and a condenser in parallel, although it may be extended to cover cases of greater generality. Assume that the generator 10 delivers a voltage having a wave form $e_0(t)$, from which is to be derived a modified signal and a motor speed control signal. The tube 19 being substantially a linear constant current device within its operating range, the anode current is a replica, in wave form, of the input voltage, and is given by $i(t)$. Using the operational notation the impedance of the resistor-condenser combination 21 is

$$Z(p) = \frac{1}{C} \frac{1}{p + \frac{1}{RC}} \quad (4)$$

and the voltage which appears across it when the current $i(t)$ flows through it is

$$e(t) = Z(p)i(t) = \frac{1}{C} \left(\frac{1}{p + \frac{1}{RC}} \right) i(t) \quad (5)$$

Expanding the operator $Z(p)$ in a series, (5) becomes

$$e(t) = R[1 - RCp + (RCp)^2 - (RCp)^3 + \dots]i(t) \quad (6)$$

which at once shows that the voltage appearing across the impedance 20—21 contains components related not alone to the first derivative of

the original signal but to an infinite series of derivatives. By use of the substitution

$$F(p) = RCp - (RCp)^2 + (RCp)^3 \dots \quad (7)$$

Equation 6 may be written

$$e(t) = R[i(t) - F(p)i(t)] \quad (8)$$

or

$$e(t) = R[i(t) - D(t)] \quad (9)$$

where $D(t)$ is the time function produced by the operator $F(p)$ operating on $i(t)$. The first term $Ri(t)$ of Equation 9 is seen to be an undistorted replica of the original signal and the second, $RD(t)$ is a measure of the deviation from faithful reproduction. No attempt will be made to point out that it is a function of the first and higher order time derivatives of $i(t)$ and results in a general way from the slowness of the circuit action in following sharp bends and steep slopes in the signal.

It is on account of the action of the circuit 19-23 in splitting the anode current into two components, one functionally similar to the original signal and the other related to the distortion which would result from passing this signal through a narrow band channel that this portion of the circuit is termed a "splitter."

The same current $i(t)$ which flows through the impedance 20-21 also flows through the resistor 23 to produce a voltage drop across it given by $Ri(t)$, since the resistances 20 and 23 have the same value. This voltage drop is applied along with the voltage drop given by Equation 8 and Equation 9 to the input terminals of the differential mixer. By reason of the push-pull input-parallel-output connection of this circuit the $Ri(t)$ component has no effect on the anode current, whereas the component $RD(t)$ is amplified, rectified, and then applied to control the driving motor speed in a sense to give rise to a signal of such a character as to be able to pass a transmission channel having a characteristic related to that of the impedance 20-21 without substantial distortion.

The above-described modifications of the signal evidently cannot be effected instantaneously. Rather, a certain time elapses between the instant at which a signal is impressed on the splitter circuit and a later instant at which the corresponding alteration in speed takes place at the recorder motor 12. This delay is indicated in Fig. 2, without any attempt at quantitative exactness, by the fact that corresponding points of the original and modified signal are displaced along the time axis, those of the modified signal occurring later than those of the unmodified signal. In order that this speed change shall take place in the correct relation to the original signal, a corresponding constant time delay should preferably be inserted in the path from the generator 10 to the recording poles 15. Apparatus for this purpose which is well known per se, may be of any suitable type and is symbolically indicated in Fig. 1 by the block 16.

The tape, bearing the expanded or compressed signal as above described, now travels past the slack portion S_1 to the pick-up poles 45 in the portion B of the tape which, as above pointed out, is driven at a constant speed by the synchronous motor 13. As the magnetized tape passes between these poles 45 a signal is generated in the windings 44.

It will be understood by those skilled in the art that, quite apart from the circuit arrange-

ments and signal modifications of the invention, the time signal so recovered is not a replica of the magnetic space signal on the portion B of the tape, but is rather the derivative of the tape signal. This arises out of the principles which govern the operation of the magnetic tape apparatus, based on the laws of electromagnetic induction. This derivative signal may easily be restored to the proper form merely by integrating it prior to transmission and for this reason it is preferred to include an integrating circuit in the signal output path, comprising a high resistance and a capacitive reactance in series, the output voltage being tapped across the reactance. The high plate resistance of the pentode tube 47 provides the necessary resistance and the condenser 48 constitutes the capacitive reactance. A resistor 48' is connected across the condenser 48 to supply a direct current path for operating voltage for the anode of the tube but takes no part in the integrating action. Satisfactory operation may be secured with a condenser 48 of 10-microfarad capacity, the resistor 48' shunting it being of 20,000 ohms resistance or more, and the tube 47 being a five-electrode tube of the type commonly designated by the code number 310-A.

It will be apparent that in the course of the operation of the apparatus above described, the slack S_1 will increase when the speed of the recorder driving motor 12 exceeds the speed of the pick-up driving motor 13 and will decrease when the recorder motor speed is less than the pick-up motor speed. Likewise the slack S_2 will increase when the slack S_1 decreases and vice versa. It may happen in the course of a particular signal that the recorder driving motor speed exceeds the pick-up motor speed by such a large amount and for such a long time that the slack S_2 would be consumed. Likewise, it may happen under opposite circumstances that the slack S_1 would be consumed. In either event, operation, as above described, ceases and signals will fail to be modified. Furthermore, the apparatus itself may be injured. To prevent both of these occurrences an auxiliary follow-up control system is provided in accordance with the invention to restore the slack portions of the tape to operative values. This auxiliary control system may be of any desired type and a mechanical relay-operated system is here shown by way of illustrative example. Two discs 55, 56 are mounted to rotate concentrically and adjacent one another, the one 55 being geared to the recorder motor 12 and the other 56 to the pick-up motor 13. Coupling or gearing mechanisms which may be of any desired type are indicated by dotted lines. The couplings are so chosen that the ratio of the disc speeds is at all times equal to the ratio of the motor speeds, although the actual amount of gear reduction in each coupling depends on the amount of tape slack which it is desired to accommodate. The discs 55, 56 are of insulating material and one of them is provided with a brush contact and the other with a number of commutator bars, for example four, as shown. Electrical connections from the one contact on the first disc and the four bars on the second disc are to be understood as being brought out from the rotary discs through slip rings in well-known manner. Such details have been omitted in order to avoid undue complexity of the drawings.

In order to understand the operation of this system, let it be assumed that the outer disc 55 bears the four bar contacts 1, 2, 3, 4 and is cou-

pled to the recorder motor 12 and that the inner disc 56 bears the single brush contact 5 and is coupled to the pick-up motor 13. Further, let it be assumed that both discs rotate in a counter-clockwise direction, and that the recorder motor 12 is lagging the pick-up motor 13 so that the slack S_1 will, if this condition continues too long, eventually be drawn taut. The relative motion of the inner disc 56 is then in a counter-clockwise direction with respect to the outer disc 55 so that the brush 5 will meet the bars 1 and 2, in the order named. As it meets and passes the first bar, a current will momentarily flow from the battery 57 through a relay 1a and to ground. This will momentarily raise the tongue b which, however, will have no other effect since the circuit of battery 58, tongue contact b, and ground is already open at tongue contact c. As the lag increases the second bar 2 will next be contacted, and current will flow from the battery 57 through a second relay 2a to ground. This will pull the tongue c of the relay 2a downward to close the contact c and the latter will thereupon be held down by current flowing from the battery 58 through contacts b and c. At the same time, current in the relay 2a will move the tongue d upward to open the contact at d which is connected across the portion 39d of the resistor 39 which was theretofore short-circuited by the normally closed contact at d. This effectively places the grid return of the speed control tube 37 nearer to the positive end of the resistor 39 as a whole and raises its absolute potential or reduces the grid bias of this tube which results in an increase of its plate current and an increase in the speed of the recording motor 12. The tapped resistor 39 and the battery 40 connected across it, as well as the motor control tube characteristic, are so chosen that the resulting increase in the recorder motor speed is substantially the maximum of which this motor is capable and greater than the speed of the pick-up motor under any and all conditions of signal distortion or rapidity of fluctuation. Therefore the recorder motor 12 will proceed to overtake the pick-up motor 13 and the slack S_1 will increase again and the direction of relative motion of the two control discs 55, 56 will be reversed. The brush 5 of the disc 56 then leaves bar 2 and returns in the direction from which it came. When it passes bar 1 relay 1a is momentarily energized thus lifting tongue b and so opening the holding circuit of relay 2a and permitting the tongues c and d of the relay 2a to return to their original positions under the action of their restoring springs. By this time, in case the rapidity of fluctuation of the signal has not changed materially, the auxiliary control process will be repeated. If, however, the signal rapidity of fluctuation has been largely altered in the interim, the recorder motor 12 may be traveling at a speed equal to that of the pick-up motor 13 or even greater under the control of the distortion signal alone. In this event, the disc 56 may rotate in a clockwise sense with respect to disc 55 until contact No. 4 is reached by the brush 5. The operation as the brush contact strikes bar contacts 4 and 3 in succession is exactly the same as the operation above described in connection with contacts 1 and 2. It results in removing the short circuit theretofore placed across the portion 39a of the resistor 39 and thus increasing the control grid bias of the motor control tube 37 which reduces the plate current of that tube and therefore the recorder motor speed. The constants of the circuit are

preferably so chosen that the resulting reduction in motor speed brings the speed down substantially to a certain minimum value, the lowest of which it is capable in the course of operation, and lower than that of the motor 13.

The effect of the above-described auxiliary control circuit is of course to alter the recorder motor speed in a manner independent of the influence of the distortion signal. Therefore, during the intervals in which the auxiliary control system operates, the signal time base may be compressed when it would otherwise be expanded or expanded when it would otherwise be compressed and distortion naturally results. However, these intervals are of such short duration and occur so infrequently that the resulting distortion present in the ultimate reproduction is scarcely noticeable. It will further be understood that although this auxiliary control or follow-up system, while believed to be novel both in itself and in the combination shown, is not essential to the operation of the remainder of the system of the invention. It is introduced only to permit the use of tape slack portions S_1 and S_2 which are not unduly long.

A resistor 38 is included in series in the anode circuit of the motor control tube 37 and the voltage drop across this resistor, whose fluctuations have the same wave form as the current which drives the recording motor 12, is impressed on a filter 51 and transmitted over an auxiliary control channel 52 to a receiver, there to control the speed changes of a corresponding tape-driving motor. Either the main modified signal or the auxiliary speed control signal may be modulated onto suitable carrier waves prior to transmission or both of them may be so treated. Apparatus of this character and for this purpose is well known per se and will not be described, and in the interests of simplicity has been omitted from the drawings. The filters shown in the main signal channel and the auxiliary control signal channel, respectively, do not form an essential part of the invention. Since, however, one of the chief advantages of the invention lies in the fact that signals which would ordinarily require a wide channel can now, by reason of the invention, be transmitted over a considerably narrower channel, it results that by virtue of the invention several such signals may be transmitted over a channel which would otherwise be capable of carrying only a single one. The filters, whose transmission bands should be as wide as necessary to transmit the modified signal of the invention without excessive distortion, are included in the drawing to prevent interference, cross-talk and the like between signals from one transmitter in accordance with the invention and those from another.

Fig. 3 shows simplified apparatus for receiving the modified signals of the invention and translating them into their original unmodified form. A tape 61 of two principal working portions C, D separated by slack portions S_3 and S_4 is arranged to be driven by two independent motors 62, 63. The incoming signal which may be received by appropriate apparatus of types well known per se, passes first through a filter 64 of a characteristic corresponding to that of the filter 49 at the transmitter end of the line 50. This filter 64 serves merely to exclude extraneous signals which may be transmitted over the same line but does not form a part of the signals to be treated. The modified signal is then impressed, after amplification as desired by means

not shown, on recording windings and poles 65 on the portion C of the magnetizable tape which is driven by the recording motor 62 at a constant speed, preferably the same as the speed of the transmitter pick-up motor 13. The tape 61 then bears a space signal which is a replica of the modified time signal received at the input terminals of the apparatus. This modified space signal travels over slack S₃ to the portion D of the tape where it is recovered by a pick-up pole 66 and associated windings as shown, integrated by a pentode tube 67 and reactive circuit 68, 68' in a manner precisely similar to that hereinabove described in connection with Fig. 1, whence it may be supplied from the output terminals 69 to any suitable reproducer apparatus. However, at the time it is recovered, the modified space signal on the portion D of the tape is being advanced at varying speeds by the motor 63 which is driven through an amplifier 70 by the control signal received over the pilot channel 52 and through a filter 71 and a delay circuit 72, included to compensate for the unavoidable delay between the recorder 65 and the pick-up pole 66. The delay circuit 72 may be similar to the circuit 16 at the transmitter or may be of any desired type. The control signal includes or contains information both as to the necessary speed variations for the pick-up motor 63 and also as to the departures from the control signal introduced by the auxiliary control device at the transmitter. Thus the speed of the receiver pick-up motor 63 varies from instant to instant in step with the speed of the recorder motor 12 at the transmitter and in a manner to speed up recovery when the time scale of the signal has been expanded and to slow it down when the time scale has been compressed. At the same time its operation is momentarily interrupted by the auxiliary control apparatus at the transmitter when either of the two slack portions C, D of the tape would otherwise be consumed.

As a result, the compressed signal is expanded and the expanded signal compressed to deliver the original signal in its unmodified form to a reproducer.

Fig. 4 shows an alternative form of receiver of somewhat greater complexity which may be employed in case it is desired to dispense with the auxiliary pilot channel 52 from transmitter to receiver. The magnetic tape 61, recording poles 65 and associated windings, pick-up poles 66 and associated windings, driving motors, input and output circuits may be identical with those above described in connection with Fig. 3. However, instead of the pick-up motor speed being governed by the auxiliary signal received over the pilot channel, the pick-up motor speed is governed by the modified signal itself as it appears at some part of the receiver apparatus. For this purpose, a circuit arrangement, which may be identical with that shown in Fig. 1 and hereinabove described in connection with that figure, and comprising a splitter, differential mixer, biased full wave rectifier and motor control tube, is provided. The signal input to this circuit is taken through a blocking condenser 80, for example, from the output of the integrator circuit 68.

The operation of this circuit is as follows: The received signal is recorded by poles 65 on the portion C of the tape, driven at constant speed by the motor 62, as a space signal. This space signal is recovered at portion D at variable speed.

This recovered signal is first integrated by the circuit 67, 68 in the manner above discussed in connection with Fig. 1 and then passed to the splitter circuit. A voltage drop appears across the cathode resistor 123 of the splitter circuit and another different voltage drop across the impedance 121 in the anode circuit of the splitter, the difference between these voltage drops increasing in proportion to the rapidity of fluctuation of the input signal and therefore in proportion to the degree of compression which has taken place. The greater this voltage difference, the greater the rectified output of the rectifier load 136 and the greater the current in the anode circuit of the speed control tube 137 which drives the pick-up motor 63. Thus, as space signals whose rapidity of fluctuation is higher than the average appear at the portion D of the tape, the speed of the motor 63 which drives this portion of the tape is increased with the result that the rapidity of fluctuation of the derived time signal impressed on the integrating tube is still further increased and vice versa. Choice of identical component parts for corresponding portions of the receiver and transmitter apparatus will therefore result in restoration of the signal at the output terminals 69 of the receiver to its original form. An auxiliary control circuit is also included. It serves a purpose similar to that served by the corresponding transmitter apparatus and may be similar thereto or a modification thereof, as desired.

Fig. 5 shows an alternative arrangement of the transmitter apparatus making use of a regressive motor speed control or feedback. The magnetic tape, recording and pick-up poles and windings 14, 15, 44, 45 and driving motors are identical with those of Fig. 1 with the exception of an interchange between the constant speed motor and the variable speed motor, in that the motor 12' which drives the recording portion A of the tape is now a constant speed motor, whereas the motor 13' which drives the recovery portion B of the tape is now the controlled motor. Furthermore, the mixer, rectifier and motor control circuit, as well as the auxiliary follow-up control system and the integrating circuit are similar to those of Fig. 1 and require no further detailed description. A difference between the splitter circuit of Fig. 5 and that of Fig. 1 will be fully explained below.

The operation of the apparatus of Fig. 5 is as follows: The original unmodified signal from the generator 10 is recorded on portion A of the tape, driven by the motor 12' at constant speed to form a space signal replica thereof. The latter moves on to the portion B, where the tape travels at variable speed. There it is picked up in its derivative form by poles 45 and windings 44 and fed to the integrator circuit 47, 48. From the integrator circuit the energy follows two paths, the one to the output filter 49 and through the latter to the transmission line 50, and the other into the modifying circuit which may be identical with that of Fig. 1. From the modifying circuit it then passes by way of speed control tube 37 and the associated resistor 38 to the recovery motor 13' which varies the speed of the portion B of the tape in such fashion as to reduce its speed when the rapidity of fluctuation of the space signal is high and increase it when the rapidity of fluctuation is low. Thus there is here an inverse relation between tape speed and rapidity of fluctuation of signal whereas in the

modification of Fig. 1 the corresponding relation was direct. The difference is due to the fact that here the variable speed motor 13' drives the pick-up portion B of the tape whereas in Fig. 1 the variable speed motor 12 drives the recording portion A of the tape. This different mode of operation may be secured merely by proper choice of the polarity of the input terminals of the speed control tube 37 with respect to the voltage drop in the rectifier load resistor 36 in the two cases.

Terminals 52 are connected to the resistor 38 at which a control signal may be tapped for transmission over a pilot channel as in the case of Fig. 1, if desired.

Because of the fact that in the arrangement of Fig. 5 the input energy to the splitter circuit is derived from the pick-up winding 44 from the variable speed portion B of the tape 11 and therefore in itself constitutes a modified signal, this apparatus must be capable of operation on a smaller margin of distortion signals than was available in the apparatus of Fig. 1. That is, in the apparatus of Fig. 1, the signal delivered to the differential mixer was the difference between the original unmodified signal and the signal as modified by the impedance 20—21 which might have a frequency characteristic similar to that of the transmission line 50. This difference signal might therefore be a signal of considerable magnitude. In the case of Fig. 5 on the other hand, the input energy to the differential mixer circuit comprises the difference between the signal as modified in accordance with the invention and the same signal as further modified by passing through the impedance 20'—21'. In order that the apparatus may operate in a satisfactory manner, it is therefore advisable to choose the impedance 20'—21' as one having a characteristic of more exaggerated form than that of the transmission line 50; that is to say, the mean slope of its attenuation-frequency characteristic should be steeper than the mean slope of the corresponding characteristic for the transmission line. Regressive control or feedback apparatus as shown in Fig. 5 is therefore required to have greater sensitivity than apparatus of the progressive control type as shown in Fig. 1, but the various well-known advantages which are obtainable with feedback apparatus are believed to justify its use in this connection.

Fig. 6 illustrates receiver apparatus which may be employed in conjunction with the transmitter of Fig. 5. Each of the component parts of the system shown in Fig. 6 is similar to a corresponding part of one of the other figures, only the arrangement or order being different. The incoming modified signal, after being passed through a filter 64, is split into two paths, one of which is impressed directly through the poles 65 onto the portion C of the tape 61, which is advanced at varying speeds by the motor 62'. The space signal so formed is recovered by pick-up poles 66 at the part D of the tape which is advanced at constant speed by the motor 63'. After being integrated by a pentode 67 and negative reactance circuit 68 in the manner described above, this signal constitutes the output of the receiver. At the same time the other path of the modified signal is fed to a splitter from which are separately derived the distorted and undistorted signals in the manner above described. These signals are differentially mixed to provide a distortion signal which is thereupon rectified and supplied to the speed control tube 137 whose output current in turn controls the motor 62'.

driving the recording portion C of the tape. The input terminals of the speed control tube 137 should be so poled with respect to the voltage drop in the rectifier load resistor 136 that an increase in the distortion signal results in a decrease of the plate current of the speed control tube 137 and therefore a decrease in recording speed. This in turn results in a compression of the space signal on the tape as compared with the incoming time signal when the latter has a high rapidity of fluctuation and vice versa.

In the detailed description of the auxiliary control circuit of Fig. 1, it was stated by way of example that the discs rotated in a counter-clockwise direction. For the auxiliary control circuits of Figs. 4, 5 and 6 it will be understood by those skilled in the art that care should be taken in the choice of rotation direction that it be such that the action of the device is to relieve the situation created by excessive lag or overtaking by one motor with respect to the other, and not to accentuate it.

It will be observed that in Figs. 1 and 4, motor speed is caused to increase directly with rapidity of signal fluctuation whereas in Figs. 5 and 6 the reverse is true. Under some circumstances, one form of the invention in this regard may be of advantage and under other circumstances another form may be preferable. It is of advantage, however, to maintain a paired relation between the transmitter and receiver in each case in the sense that if the pick-up motor is controlled at the transmitter, the recorder motor should be controlled at the receiver and vice versa. This permits the use of similar apparatus at both transmitter and receiver. Otherwise, if it were desired to control the pick-up motor, for example, both at the transmitter and at the receiver, it would be necessary to increase the speed of the one, and decrease the speed of the other in an inverse manner for one and the same amount of rapidity of signal fluctuation. At the expense of some additional apparatus, however, this result may be secured by the use of a suitable shaping device such, for example, as that described in application Serial No. 342,601, filed June 27, 1940.

Various other orders of arrangement of the component parts of the apparatus of my invention and various other sequences of the operations which take place therein will occur to those skilled in the art and may be employed in the place of those hereinabove discussed.

It is, of course, unnecessary that the storage medium employed be a magnetic tape. Storage devices of many other kinds are known, any one of which may be employed with appropriate minor modifications in the system of the invention without in any way departing from the spirit thereof.

It will be noted that in the case of each of the modifications hereinabove described, the signal is first recorded on a storage medium and thereafter recovered therefrom. In this way it is possible to effect compression and expansion of the frequency spectrum of a signal by expanding and contracting the artificial controllable time base provided by a space signal moving at controlled speed. Since the formation of a record on a storage medium affords a convenient controllable time base, the invention offers added advantages in the case of image or television signals over what is offered in the case of telephone signals, for example on account of the fact that the original unmodified signal with which the process is started and the final signal with which the process is concluded are both essentially space signals as dis-

tinguished from time signals. Advantage is taken of this fact to provide simplified apparatus for use with image signals in particular, the apparatus heretofore described being of more general application.

Referring to Fig. 7, a television pick-up device is provided which may be of any of the known types, the device here chosen by way of illustrative example being of the so-called "image dissector" type. The construction, mode of operation and the principles upon which it is based are well known per se and will only be briefly referred to. For a fuller description reference may be made, for example, to Farnsworth Patent No. 1,773,980, August 26, 1930, and to "Television engineering," by J. C. Wilson at page 381. Briefly, an optical image of a field of view to be transmitted is imaged on the extended surface of a photosensitive cathode 200 inside of an evacuated envelope and a phalanx of electrons emitted from this cathode travels down the axis of the envelope of the tube under the joint action of an accelerating screen electrode 201 and a focusing coil 202 to a shield 203 containing an aperture 204 behind which is placed an anode 205. This electron stream is caused to swing back and forth across the aperture 204 both horizontally and vertically by magnetic fields due to currents flowing in horizontal scanning coils 206 and vertical scanning coils 207, each pair of which is supplied with current from a suitable scanning current source. Electrons of the phalanx strike the anode 205 behind the aperture 204 in proportion to the brilliance of illumination of that point of the cathode 200 at which they originated, and the anode current so formed varies in time in a manner related to the variations of the optical image from point to point. Thus the device is essentially one for converting a space signal or record into a time signal. If desired, an electron multiplier stage may be included within the same envelope as the dissector apparatus proper in order to increase the strength of the electron signal before its conversion into a voltage signal.

In accordance with the invention the time signal output of the device in the form of an electric current flows through a resistor 208, an anode battery 209, 210 or other suitable current source and back to the cathode 200. The resulting voltage drop across the resistor 208 is impressed on the input terminals of a splitter circuit 19—23 which separates the signal into a modified and an unmodified component. These two component signals are differentially mixed by the tubes 25, 26 to provide a difference signal which is then rectified by the tubes 31, 32 to provide a control signal, precisely in the manner hereinabove described in connection with Figs. 1 to 6, inclusive. The sole differences in the circuit as thus described have to do with the substitution of capacitive for inductive couplings between stages. These are dictated by the high frequencies which may be expected to be encountered in the circuits of Figs. 7 and 8.

This distortion signal is now utilized to control the rate at which the electron image scans the aperture 204, and for this purpose modified saw-tooth wave generators are provided. The conventional features of the saw-tooth wave generator for producing the horizontal or line sweep may comprise, for example, a condenser 215, a resistor through which this condenser is charged at a comparatively slow and preferably steady rate, as by a battery 220, and a discharging device, for example a gas discharge tube 221 through which the condenser is discharged at a

comparatively rapid rate when its voltage reaches a preassigned value, whereupon the cycle is repeated. The voltage of the condenser 215, which is thus of saw-tooth wave form, is impressed on amplifying and translating apparatus 222 to produce a current of like frequency and related wave form. This current is supplied to the horizontal deflecting coils 206 to produce a magnetic field of saw-tooth wave form to deflect the electron beam past the aperture 204. The amplifying and translating apparatus 222 may be of any desired type well known per se and, therefore, in order to avoid undue complexity of the drawings, it is symbolically indicated by the block 222.

Vertical scanning apparatus for supplying current to the coils 207 to produce a magnetic field of saw-tooth wave form to effect vertical sweeping of the electron beam past the aperture 204 is provided, including the elements designated by the reference numerals 225 to 232, inclusive. This apparatus may be entirely similar to that above described with the exception of the magnitude of the condenser 225 and the setting of the discharge tube 231 or, in more complex apparatus, the magnitude and settings of the circuit elements which determine the charging rate and discharging frequency.

The discharge tube 221 is provided with a control grid 242 and the discharge tube 231 is likewise provided with a control grid 243. These grids take no part in the scanning or speed control operation. They serve to control the return of the beam after each frame scan as described hereinafter.

The manner in which the saw-tooth wave voltage of the condensers 215 and 225, and therefore the horizontal and vertical scanning rates of the electron beam, may be modified in accordance with the distortion signal derived from the rectifier is as follows. A pentode tube 216, characterized by high but controllable internal plate circuit resistance is selected as the charging resistor and the distortion signal which appears across the resistor 36 in the rectifier output is impressed on the control grid of the pentode 216. When the distortion signal current in the rectifier anode circuit is large, the potential of the upper end of the resistor 36 is reduced with respect to its lower end. Under these conditions, the negative control grid bias of the charging tube 216 is increased, the tube's internal resistance is increased, the charging rate of the condenser 215 is reduced and the speed of sweep of the electron beam past the aperture 204 is reduced also. When, on the other hand, the distortion signal is low, the negative grid bias and internal resistance of the tube 216 are reduced and the charging rate of the condenser 215 and the electron beam sweep speed are increased.

The apparatus provided for vertical deflection of the electron phalanx operates similarly and is similarly controlled by the distortion signals, with the exception that since in the normal course the rate of rise of the vertical scanning voltage will be a small fraction of the rate of rise of the horizontal scanning voltage, a like small fraction of the distortion signal is utilized for control. This small fraction is obtained from the output of the rectifier simply by the interposition of a loss pad 233 between the point at which the horizontal speed control signal is derived and the point at which the vertical scanning speed control signals are derived.

It will be understood that the signal impressed

on the splitter tube 19 and associated circuit is derived from the anode 205 of the dissector tube and that, since the scanning of the electron phalanx takes place in a non-uniform manner in accordance with the distortion signal, the resulting signal impressed on the splitter circuit is itself largely modified in accordance with the invention. This is on account of the fact that the energy path—from dissector to splitter to mixer to detector to scanning control and back to dissector—is a closed feedback loop. Just as in the case of Fig. 5, heretofore described, where this was the case, it is of advantage that the impedance 20'—21' in the anode circuit of the splitter tube 19 have a characteristic which is exaggerated in comparison with the characteristic of the transmission line into which the apparatus is intended to work.

In a system of this kind there is no definite limitation associated with the pick-up scanning operation, corresponding to the upper and lower limits of the angular displacement difference between the two motors in the cases heretofore discussed. However, there are important practical, though somewhat indefinite scanning speed limitations introduced by flicker and motion requirements. It is therefore arranged in accordance with the invention that vertical scans shall take place in equal times at a repetition rate set by the above requirements. If the detail of the field of view is of a high order so that the average scanning speed over the frame is reduced, scanning will commence on a new frame before its predecessor scan has been completed. If, on the other hand, the detail is of a low order, vertical deflection will continue beyond the lower margin of the field of view before the following scan is commenced. The former of these occurrences will introduce a certain amount of degradation, but it is not contemplated that this effect will be of great importance since in the usual case the detail will vary more from line to line or from one portion of a line to another than it will from frame to frame, so that scanning speed differences will be in large measure equalized over each frame period.

To effect this frame time equalization various apparatus and methods may be employed. Suitable apparatus is symbolically indicated by way of example in Fig. 7. A generator 240 is provided which delivers a voltage of constant frequency. The generator may be of any suitable type and its output voltage may indeed be of pure sine wave form. The output from this generator 240 is fed to a wave-shaping device 241, which delivers a wave which may be of square-topped pedestal form and of a frequency which may be the same as that of the sine wave voltage delivered to it or a multiple thereof. The output voltage of the shaper 241 is impressed on the control grid 243 of the vertical scanning discharge tube 231. Thus the pulse from the shaper 241 is injected into each of the saw-tooth wave generators at the frequency of the frame scan and serves to discharge the vertical scanning gas discharge tube 231 and commence the next cycle of the vertical scanning saw-tooth wave independent of the voltage value which the preceding vertical saw-tooth cycle has reached. At the same time the pulse from the shaper, which should be of a magnitude greater than the peak value of the voltage on the condenser 215, is impressed on the grid 242 of the discharge tube 221 and causes the latter to discharge independent of its instantaneous voltage, thus producing

flyback of the electron beam independent of its instantaneous position. The adjustment of the vertical scanning circuit is preferably such that the ignition voltage of the discharge tube 231 is not reached in the absence of a tripping pulse from the shaper 241. On the other hand, the horizontal scanning circuit may be adjusted to trip by itself, the final horizontal tripping in each frame being forced into coincidence with the vertical trip by the shaper pulse.

This frame period equalizing means thus serves at the same time as a means for synchronizing line scanning with frame scanning in a partial sense; that is, it insures that a new line scan will commence at the same time as each new frame scan.

In order to synchronize receiving apparatus with transmission apparatus, it is usually necessary to send some sort of synchronization information from one to the other. In accordance with the invention the frame period equalizer system is utilized as a source of such information and, accordingly, terminals marked "Sync channel" are brought out from the constant frame frequency generator 240 for this purpose.

The modified signal appears across the output of the image dissector tube and may be amplified as desired, filtered and transmitted to the receiver over the transmission channel 50 of reduced width. Either the main signal, the synchronizing signal or both may be transmitted without further modification, may be filtered, may be modulated onto a carrier, may be combined or otherwise modified in any desired manner for transmission to the receiving apparatus.

Fig. 8 shows receiving apparatus suitable for the reception and translation of the modified signals delivered by Fig. 7 and transmitted over a channel of reduced width. The incoming signals are fed at once to a splitter circuit 119—123 and are then differentially mixed by the mixing circuit 125, 126 to provide a difference signal which is then passed through the rectifier 131, 132 and supplied to a horizontal saw-tooth scanning oscillator 315—321. At the same time the distortion signal is reduced in amplitude by a loss pad 333 and supplied to a vertical scanning generator 325—331. The splitter, mixer and rectifier may be similar to those hereinabove described and need no further discussion. The horizontal and vertical saw-tooth scanning oscillators may be identical with those hereinabove described in connection with the transmitter apparatus of Fig. 7, the sole difference being that instead of a frame period equalizing generator being provided, the signals received over the auxiliary channel from the frame period equalizing generator 240 at the transmitter are themselves supplied to a shaping circuit 341 after such amplification or other treatment as may be found desirable, whereupon the impulses from the shaper, being applied to the control grids of the discharge devices 321, 341, control the discharges of the scanning condensers 315 and 325 exactly as in the case described above in connection with Fig. 7.

The output energy of each of the horizontal and vertical saw-tooth deflection generators appears, after amplification as desired, as a deflecting voltage for use in producing variable speed deflection of a reproducer element.

Any suitable reproducer may be employed, and in the interests of simplicity a cathode ray reproducer, reduced to its simplest terms is shown in the figure. It may consist of an evacuated vessel 350 containing in one end a cathode source of

electrons 351, accelerating and focusing electrodes 352, 353 connected to suitable sources 354, 355 of anode potential for directing a beam of electrons on a fluorescent viewing screen 356 at the far end of the vessel, a conductive lining 357 on the inside walls of the vessel in the neighborhood of the screen, and means, for example, metallic plates 358, 359 disposed to deflect an electron beam in two mutually perpendicular directions when suitable deflecting voltages are impressed upon them.

The reproducer is provided with a modulating electrode which serves to vary the intensity of the cathode beam in accordance with the signal amplitude. It is here shown by way of example as a grid 260 which is connected through a stopping condenser 261 to one side of the input circuit of the apparatus.

The horizontal and vertical saw-tooth scanning voltages, modified by the distortion signal as above described, may be impressed directly upon these deflecting elements so that the spot of light which appears upon the viewing screen 356 when an electron beam originating at the cathode 351 is directed upon it moves not in the uniform fashion of the usual systems or in the non-uniform fashion of systems known as "velocity modulation" systems, but in the particular non-uniform manner of this invention, traveling slowly over portions of the screen on which high detail is to be recorded and rapidly over other portions upon which low detail is to be recorded. Thus the modification of the signal by reason of the compression and expansion of its frequency spectrum in accordance with the invention is removed and the image reproduced on the viewing screen of the reproducer device is a substantial replica of the image originally projected on the photosensitive cathode of the dissector.

The cathode beam intensity is preferably further modulated in accordance with the scanning velocity by the addition of a second grid 262, to which the velocity control signal appearing across the resistor 136 is supplied. Thus as the scanning speed increases the beam intensity also increases, so that the brilliance of the luminescent spot on the viewing screen 356 may be independent of the scanning velocity.

Various modifications and rearrangements will occur to those skilled in the art, both of the particular systems shown in Figs. 7 and 8 and of the other systems of more general application, shown in Figs. 1 to 6, inclusive. Many of such modifications may be made without departing from the spirit of the invention, since each of the modifications above described and shown is to be taken as illustrative and not as essential.

For example, the invention has been described as associated with a terminal network or transmission line system of a low-pass characteristic; that is to say, one whose pass-band extends from zero frequency up to some preassigned value. It is to be understood, however, that if desired the modified signals of the invention may be modulated onto a carrier wave in accordance with known practice and transmitted over a channel whose pass band extends between two frequencies both of which differ from zero. Furthermore, there will occur to those skilled in the art various modifications of the impedance network 20-21, shown in the illustrative embodiment as a simple parallel combination of a resistor and a condenser, which will adapt the invention for use in this connection.

Either single side-band or double side-band modulation may be employed as desired.

It is further to be understood that in the above description the transmission line or filter is to be taken as illustrative only, since it is within the contemplation of the invention that a plurality of signals, modified in accordance with the invention shall be transmitted over a single transmission line. In this event these signals would normally be separated from one another by such frequency difference as may be necessary which, by reason of the invention, may be a smaller frequency difference than would otherwise be required to maintain satisfactory separation between them.

In the appended claims the expression "fluctuation rapidity" is used to designate that characteristic of a signal wave form which corresponds to the characteristic "frequency band width" of the equivalent spectrum comprising the group of sine wave components which combine to make up the signal. It is thus to be distinguished from a related but different characteristic of the signal which corresponds to the frequency of any particular individual component or components of the spectrum.

The term "channel of limited band width" and the like is not intended to imply a limitation to transmission over a long path. It applies equally, in the absence of other limitations, to transmission from point to point over local apparatus such as an amplifier or other transmission means of limited band width.

What is claimed is:

1. In a signaling system, a source of an original signal characterized by frequency band width variations, a transmission channel having a pass-band width of the order of the average band width of said signal, and means for compressing wide band portions of said signal and expanding narrow band portions of said signal under control of the first and higher order time derivatives of said signal without substantial alteration of the average band width or suppression of any convolutions of said signal, whereby said compressed and expanded signal may be transmitted over said narrow band channel.

2. In a system for the transmission and reception of signals characterized by frequency band width variations, means at a transmitter station for compressing wide band portions and expanding narrow band portions of said signal under control of the rapidity of fluctuation of the wave form of said signal, means including a transmission channel having a pass-band width of the order of the average band width of said original signal for carrying said compressed and expanded signal to a receiver station, and at said receiver station means for expanding the compressed portions and compressing the expanded portions of the received signal to derive a signal having the characteristics of said original signal.

3. In a signaling system, a source of an original signal characterized by a varying frequency band width, a transmission channel of relatively narrow band width, and means for modifying said signal prior to transmission in a manner to permit transmission thereof over said channel without suppression of any convolutions thereof which comprises means for forming a record of said signal at one speed, means for recovering a modified signal from said record at another speed, means for deriving from one of said signals a distortion signal related to the components of said original signal which would

be substantially lost in transmission of said signal unmodified through said channel, and means for varying one of said speeds under control of said distortion signal in a sense to compress portions of said modified signal which correspond to portions of said original having a wide band.

4. In a signaling system, a source of an original time signal characterized by frequency band width variations, means for distorting said signal, means for balancing said signal as distorted against said signal as undistorted to provide a difference signal, and means for compressing wide band portions of said signal and expanding narrow band portions of said signal in accordance with said difference signal.

5. In an image signaling system, means for forming a record of an object field, variable speed means for scanning said record to produce a time signal, and means for causing the speed of said scanning to bear an inverse relation to the richness of detail contained in said object field, whereby the range of rapidity of fluctuation of the wave form of said time signal is reduced.

6. In a television system, an image signal translating device comprising a photosensitive surface, means for forming an optical image of an object field on said surface, means for projecting a cathode beam from said surface of intensity dependent on the tone values of said images, means for deflecting said beam, means for deriving image signals from said cathode beam as deflected, and means for varying the speed of deflection of said beam in inverse relation to the rapidity of fluctuation of the wave form of said signals and independently of said tone values.

7. In a television system, an image signal translating device comprising a photosensitive surface, means for forming an optical image of an object field on said surface, means for projecting a cathode beam from said surface of intensity dependent on the tone values of said image, variable speed means for deflecting said beam, means for deriving image signals from said beam as deflected, and means for causing the speed of deflection of said beam to bear an inverse relation to the richness of detail contained in successive parts of said image.

8. In a signaling system, a medium characterized by optical response to an electric signal applied thereto, variable speed means for translating an electric time signal into a space signal on said medium, and means for controlling the speed of translating by said translating means in accordance solely with the rapidity of fluctuation of the wave form of said time signal.

9. In a signaling system, a source of an original signal having a wave form comprising portions having a relatively high rapidity of fluctuation and other portions having a relatively low rapidity of fluctuation, means for producing a modified signal under control of the rapidity of fluctuation of the wave form of said original signal, said modified signal being of reduced wave form fluctuation rapidity over portions corresponding to the first-named portions of said original signal and of increased wave form fluctuation rapidity over portions corresponding to the second-named portions of said original signal, and means for maintaining the average wave form fluctuation rapidity of said modified signal substantially equal to that of said original signal.

10. In a signaling system, a storage medium, variable speed means for scanning said storage

medium, and means for controlling said scanning speed in accordance with the first and higher order derivatives of a signal wave form.

11. In a signaling system, a storage medium, means for recording a time signal on said medium at one speed to form thereon a space signal, means for scanning said space signal at another speed to recover a modified time signal containing all the convolutions of said original time signal, and means for varying one of said speeds under control of the first and higher order derivatives of the wave form of one of said time signals.

12. In a signaling system, a storage medium means for recording a time signal on said storage medium at one speed, means for recovering a time signal from said storage medium at another speed, means for distorting a time signal, means for balancing said distorted signal against an undistorted signal to provide a difference signal, and means for controlling the speed of one of said recording or recovery means in accordance with said difference signal.

13. In a signaling system, a storage medium, constant speed means for recording signals on said storage medium, variable speed means for recovering signals from said storage medium, said recovered signals being modified as compared with said first-named signals by speed variations of said recovery means, and means for feeding back said modified signals to said recovery means to control said speed variations.

14. In a signaling system, a storage medium, signal recording means arranged for movement relative to said storage medium, signal recovery means arranged for movement relative to said storage medium, means for controlling the speed of one of said movements in accordance with signal characteristics, and auxiliary means for modifying said control under control of the separation, as measured along said storage medium, between said recording means and said recovery means.

15. In a signaling system, a storage medium, means arranged for movement at one speed relative to said storage medium for recording signals thereon, means arranged for movement at another speed relative to said storage medium for recovering signals therefrom, means for varying one of said speeds under control of the rapidity of fluctuation of the wave form of said signals, whereby the separation of said recovery means from said recording means is increased and decreased, and means for restoring an intermediate value of said separation when said separation exceeds or falls below stipulated limits.

16. In a signaling system, a circuit arrangement including an impedance element having a stipulated frequency characteristic and a resistor, means for delivering signal energy to said circuit arrangement, means for deriving an undistorted signal from said resistor, separate means for deriving a distorted signal from said impedance element, means for mixing said distorted signal with said undistorted signal in opposite phase to produce a different signal, means for rectifying said difference signal, and means for utilizing said difference signal as rectified to modify the original signal in a manner to reduce said difference signal.

17. In combination with an original signal, a splitter circuit comprising a discharge device having in its output circuit a resistor and an impedance element, a mixer circuit having balanced input terminals connected to said resistor and to

said impedance respectively and having parallel-connected output circuits, and means for modifying the fluctuation rapidity of said original signal under control of current drawn from said mixer circuit.

18. In a signaling system, a storage medium, means for impressing a space signal on said medium, means for scanning said space signal at variable speed to derive a time signal containing convolutions corresponding to all the details of said space signal, and means for controlling said scanning speed in accordance with the first and higher order derivatives of the wave form of one of said signals.

19. In a signaling system, a storage medium, means for recording a space signal on said medium at a variable speed, means for scanning said space signal to derive a time signal containing convolutions corresponding to all the details of said space signal, and means for controlling said recording speed in accordance with the first and higher order derivatives of the wave form of one of said signals.

20. In a television system, means for forming an electron image of an object field, means for sweeping said image over an aperture, means for collecting electrons from said image as it is being swept past said aperture to derive a time signal, and means for varying the speed of sweep in inverse relation to the richness of detail contained in successive parts of said image and independently of the tone values of said successive image parts.

21. In a signaling system, a source of an original signal characterized by a relatively wide range in the rapidity of its wave form fluctuations, a transmission channel capable of passing signals having a narrower range of wave form fluctuation rapidity, and means for reducing the fluctuation rapidity of rapidly fluctuating portions of said signal wave form and for increasing the fluctuation rapidity of slowly fluctuating portions of said signal wave form while maintaining the average fluctuation rapidity of said signal wave form unchanged to bring said signal within said narrower range, whereby said signal as modified may be transmitted over said channel.

22. In a signaling system, a source of an original signal having a varying information content and a wave form $e(t)$, a transmission channel of limited information-carrying capacity, means for translating said signal into a modified signal having a wave form

$$e\left(\int_0^t \rho dt\right)$$

where ρ is a quantity which varies throughout the duration of said original signal in inversely relation to the information content of said original signal, and means for transmitting said modified signal over said channel.

23. In a signaling system, means for producing a distortion signal related to the distortion which would be introduced into an original signal by passage through a channel having a stipulated attenuation-frequency characteristic which comprises a path carrying a current having the wave form of said original signal, two impedance elements connected in series in said path, one of said elements having a substantially flat attenuation-frequency characteristic and the other of said elements having a characteristic simulating that of said channel, separate means for deriving voltage drops from said elements, means for balancing said voltage drops against each other, means for deriving a difference voltage from said balancing means, and means for reducing the range of fluctuation rapidity of said original signal under control of said difference voltage.

24. In a television system, a scanning element, means for causing said scanning element to progress along a rectilinear path at a variable speed in one direction to scan a line of a field of view, means for causing said element to progress in a direction perpendicular to said first-named direction at a lesser variable speed to cause said rectilinear scanning path to adopt successive positions with respect to said field of view, said last-named variable speed bearing a desired constant ratio to said first-named variable speed, and means for causing both of said variable speeds to be proportional to the richness of detail of that portion of the field of view instantaneously scanned.

25. In the signaling art, the method of modifying a signal for transmission over a channel of limited band width which comprises reducing the fluctuation rapidity of rapidly fluctuating portions of the signal wave form and increasing the fluctuation rapidity of slowly fluctuating portions of the signal wave form while retaining all the convolutions of said signal wave form.

26. In the signaling art, the method of modifying a signal for transmission over a channel of limited band width which comprises reducing the fluctuation rapidity of rapidly fluctuating portions of the signal wave form and increasing the fluctuation rapidity of slowly fluctuating portions of the signal wave form under control of the first and higher order derivatives of the signal wave form.

27. The method of adapting a signal to transmission over a channel of limited width, which comprises forming a space signal, scanning said space signal to derive a time signal containing all the convolutions of said space signal, and varying the speed of said scanning in a fashion to cause said speed to be proportional to the richness of detail of said space signal.

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