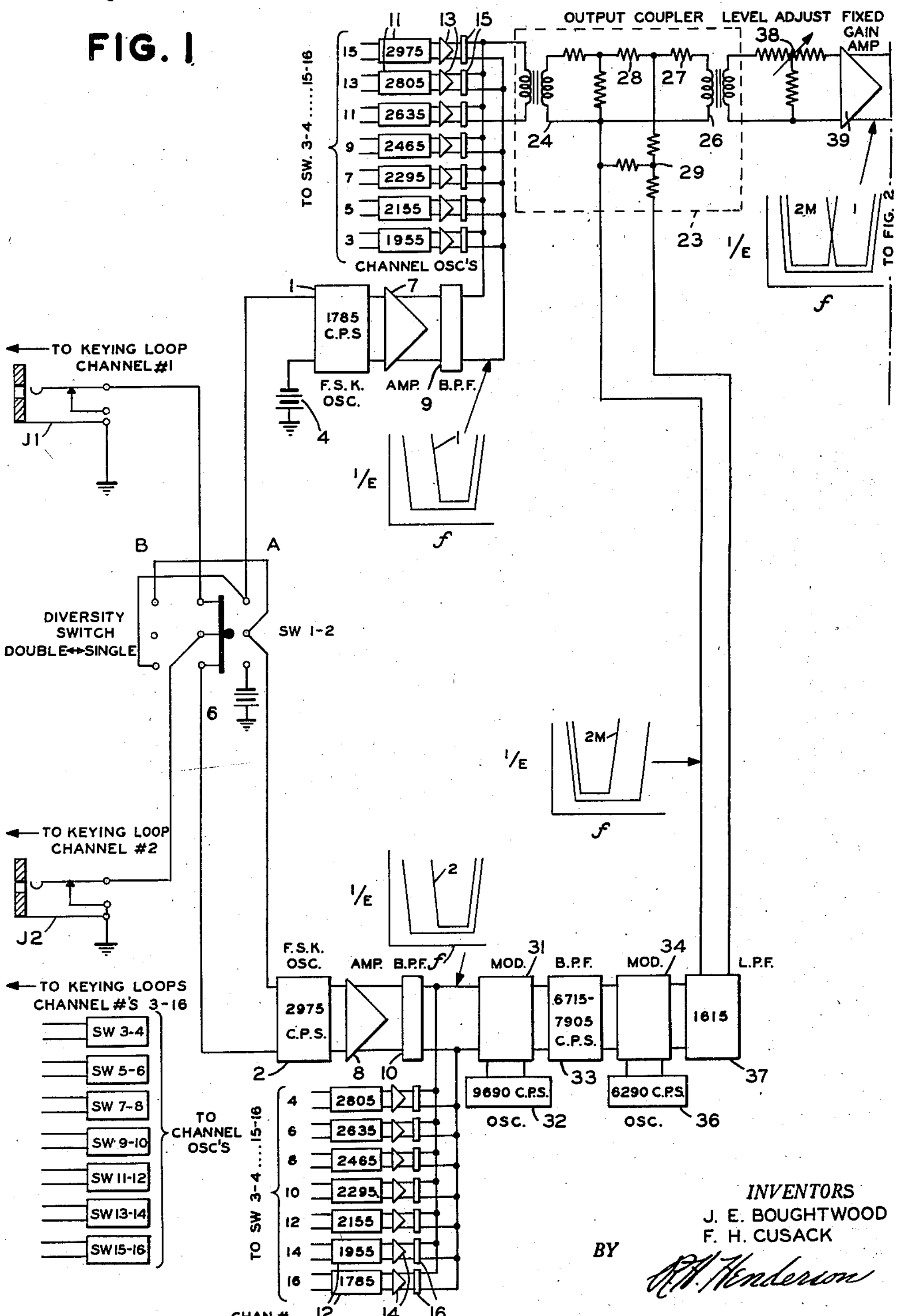
Aug. 11, 1959 J. E. BOUGHTWOOD ET AL 2,899,548

DIVERSITY TELEGRAPH SYSTEM

Filed April 22, 1955 5 Sheets-Sheet 1

FIG. I



INVENTORS
J. E. BOUGHTWOOD
F. H. CUSACK

BY R. W. Henderson

ATTORNEY

DIVERSITY TELEGRAPH SYSTEM

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FIG. 2

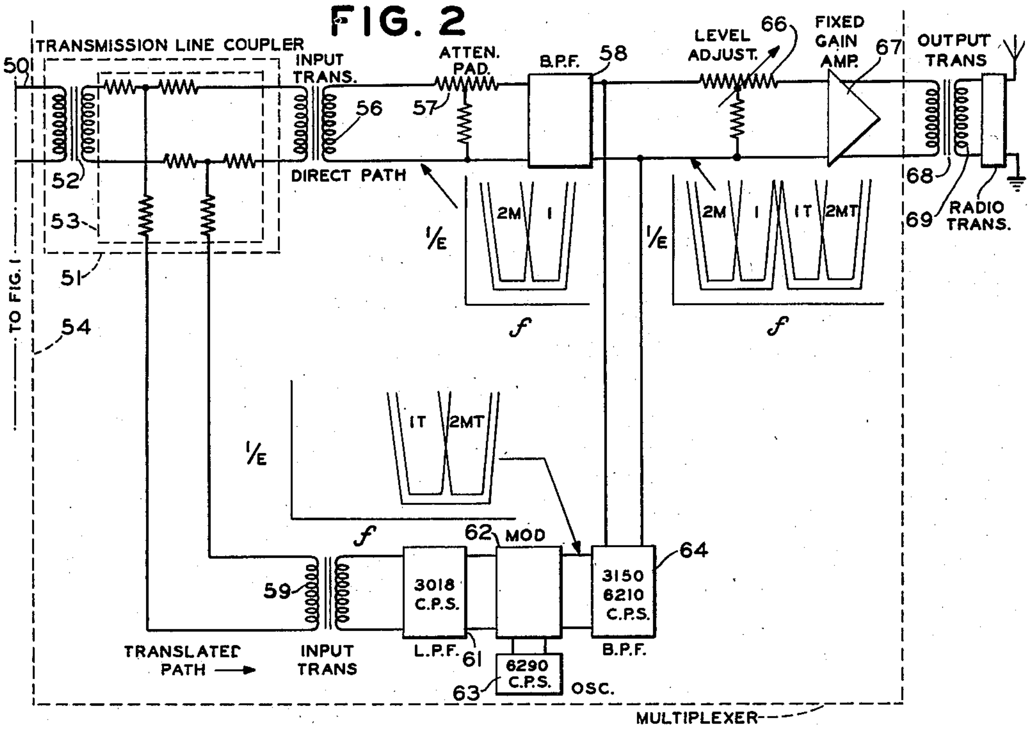


FIG. 9

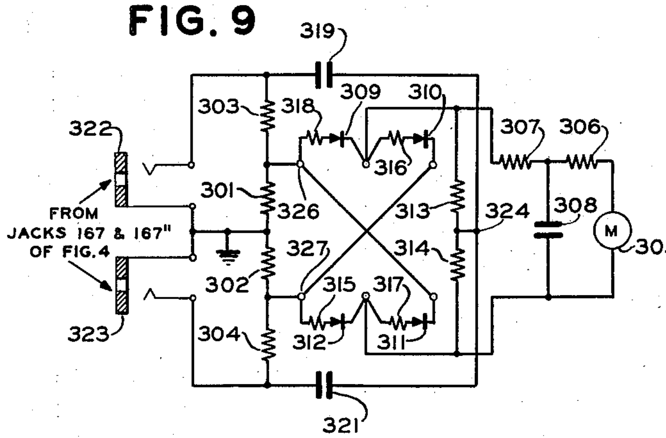
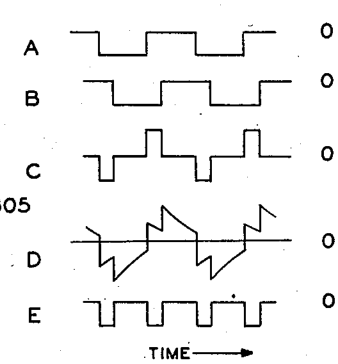


FIG. 10



INVENTORS
J. E. BOUGHTWOOD
F. H. CUSACK
BY R.H. Henderson
ATTORNEY

DIVERSITY TELEGRAPH SYSTEM

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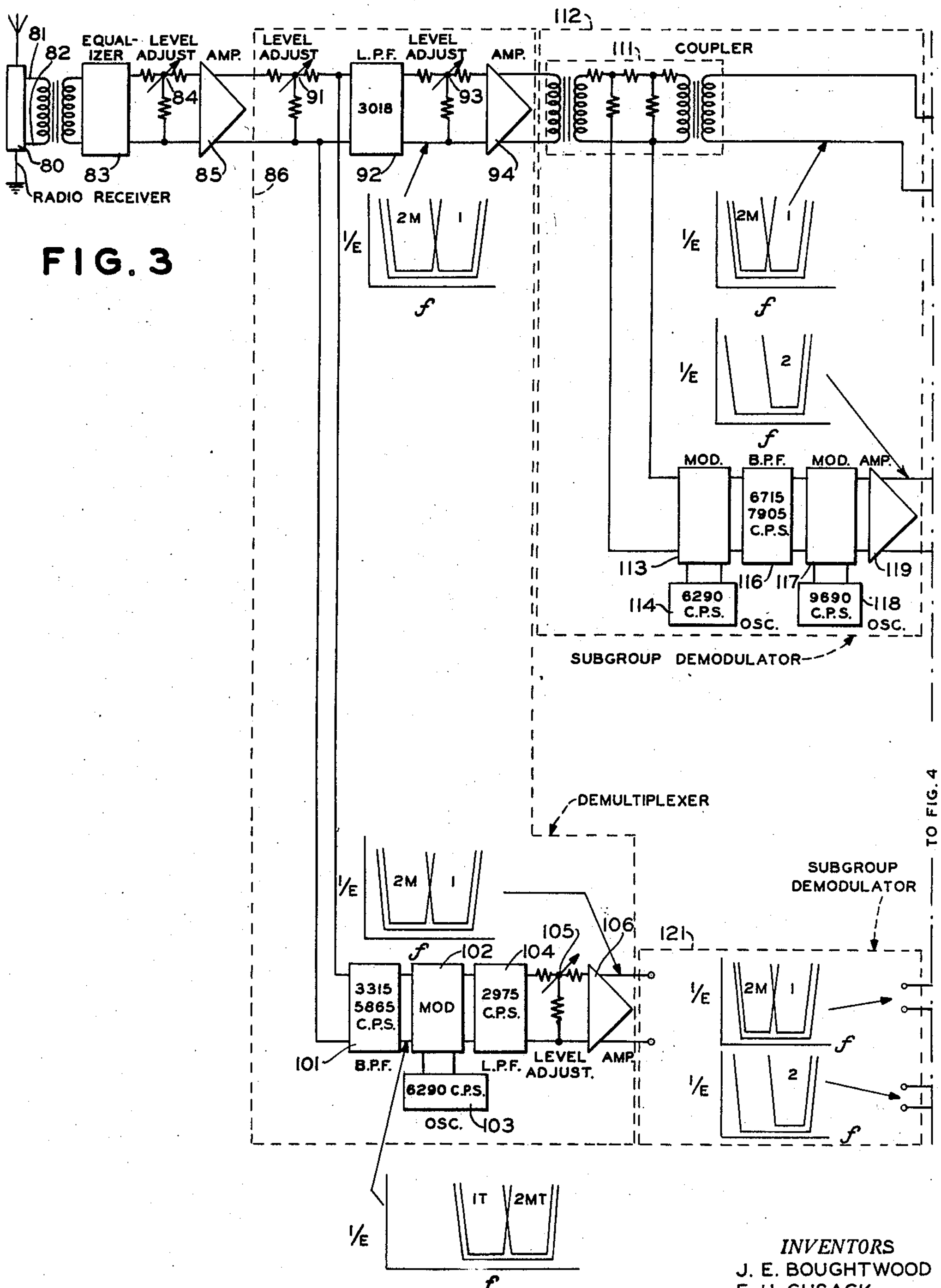


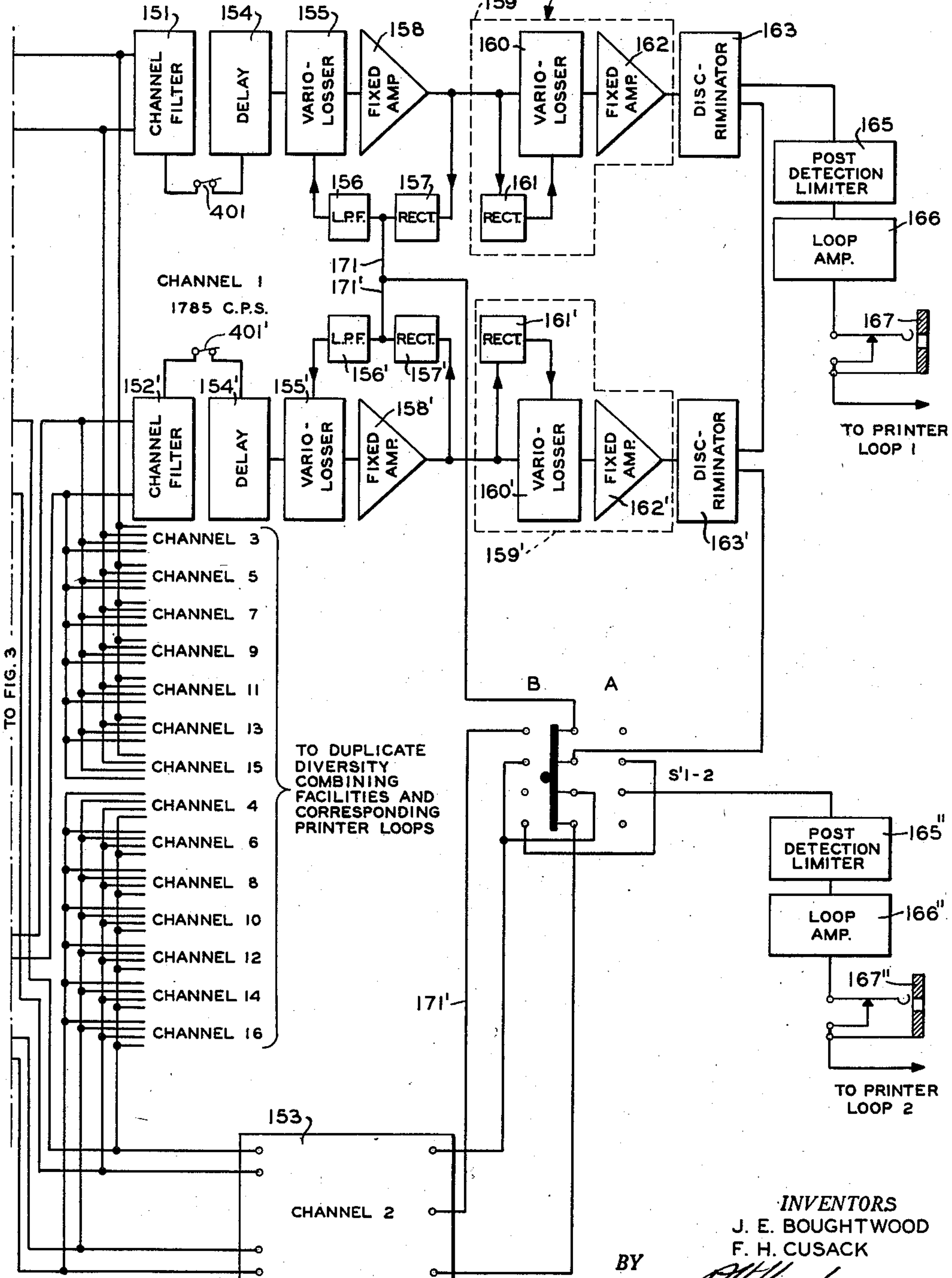
FIG. 3

INVENTORS
J. E. BOUGHTWOOD
F. H. CUSACK

BY R. H. Henderson

ATTORNEY

FIG. 4



INVENTORS
J. E. BOUGHTWOOD
F. H. CUSACK

BY R. H. Henderson

ATTORNEY

DIVERSITY TELEGRAPH SYSTEM

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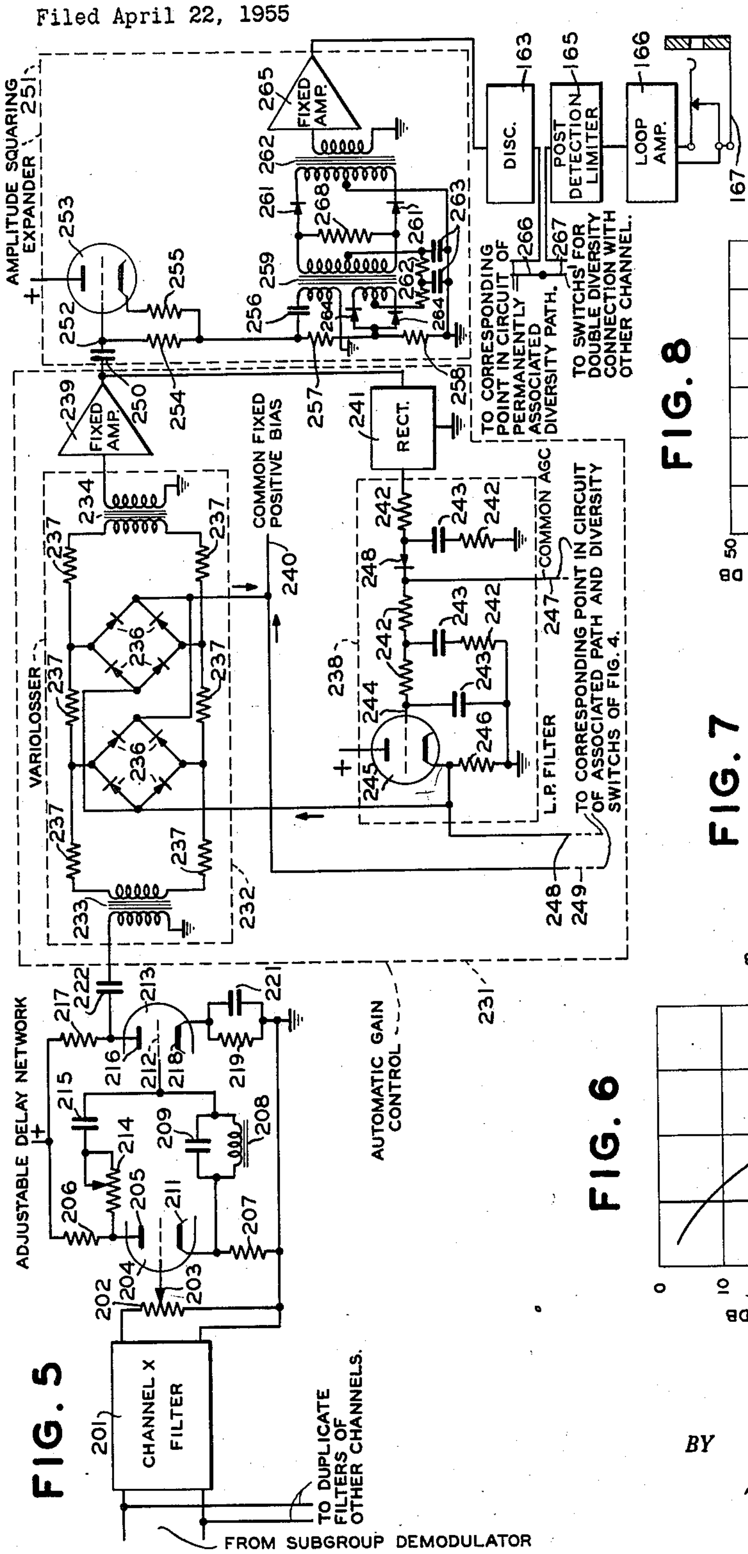

FIG. 5

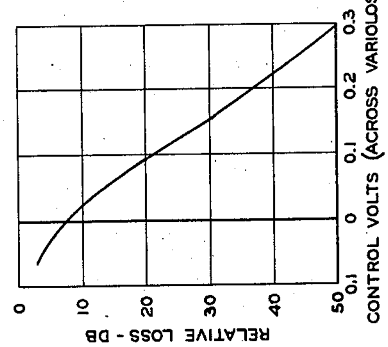

FIG. 6

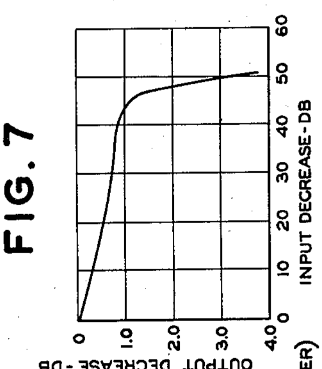

FIG. 7

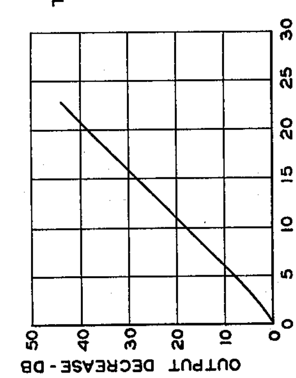

FIG. 8

INVENTORS
J. E. BOUGHTWOOD
F. H. CUSACK
BY [signature]
ATTORNEY

United States Patent Office

2,899,548

Patented Aug. 11, 1959

2,899,548

DIVERSITY TELEGRAPH SYSTEM

John E. Boughtwood, Halesite, and Frank Howard Cusack, Spring Valley, N.Y., assignors to The Western Union Telegraph Company, New York, N.Y., a corporation of New York

Application April 22, 1955, Serial No. 503,052

17 Claims. (Cl. 250—8)

This invention relates to communication by radio-telegraphy, and more particularly to an improved system of diversity radiotelegraph operation for increased reliability under adverse conditions of transmission.

When a telegraph transmission channel is subject to severe random variations, such as are caused by fading and interference, which damage the intelligibility of the received signal, one effective method of improving performance is to provide several transmissions thereof either sequentially or simultaneously over different paths, or by different methods so that they will be differently affected by the random variations. The most favorable received signal can then be selected automatically, in order to provide the best reception. In addition to this, it is clear that in general, however much it may be impaired in transmission, each such signal contains some remaining signal intelligence, so that a further improvement in results can be effected if the intelligence of the several signals can be added, without at the same time adding the components of interference which each contains.

This is accomplished in the instant invention by providing duplicate frequency shift modulation telegraph signals occurring in suitably separated portions of the audio spectrum, comprising a diversity telegraph signal at audio frequencies. This signal is used to modulate a radio carrier transmission, either singly, if interference conditions are not severe, or by means of the simultaneous transmission of two modulated carriers having different frequencies to provide further frequency diversity in the radio frequency spectrum or having different transmission paths to provide space diversity reception, when required.

Reception of the diversity pairs of signals is accomplished with an automatic gain controlled amplifier in each diversity channel, so constructed that the stronger of the two diversity signals is always amplified to a constant level while the weaker signal is amplified by an amount just sufficient to enable it to retain the same proportionate strength that it bore to the stronger signal before amplification. After this preliminary treatment which is intended to provide a relatively uniform level of excitation for the following equipment, and to eliminate any amplitude modulation present in the received signals in order to realize the well known advantage of frequency modulation, the signals are again independently amplified by ratio-squaring expanders in such a manner as to provide an output voltage from each which is proportional to the square of its input voltage. By then combining these output voltages through series addition in a discriminator in order to demodulate the audio carrier, it is found that the resulting telegraph signal corresponds to the instantaneous sum of the telegraph signals in the diversity channels, whereas the random noise components appear only as the square root of the sum of the squares of the noise components of the individual channels. This represents an improvement which amounts to doubling the ratio by which the signal exceeds the noise, in the case of equal signals in the diversity paths. A further and similar improvement of the signal to noise ratio is effected by the use of double diversity transmission and reception, that is to say, the use of plural transmission channels at both radio frequency and audio frequency levels, as above mentioned.

Economy of radio spectrum space renders it desirable to provide the maximum number of intelligence channels in the minimum of radio bandwidth that is consistent with reliability of operation and adequate message speed. For this purpose, provision is made for space diversity operation of the instant equipment wherein 16 transmissions of frequency shift telegraph signals are propagated on a 3 kc. sideband of a suppressed carrier radio wave. Received signals from a pair of spaced receivers are then amplified in distinct diversity paths as above described for summation to produce an improved reception signal. In accordance with a preferred embodiment of the instant invention, 32 transmissions of frequency-shift modulation telegraphy are employed to provide 16 intelligence channels when operating in single frequency diversity, or 8 intelligence channels when operating in double frequency diversity. This mode of operation of the said preferred embodiment is employed in cases where space diversity operation is not practical. These are transmitted on two high frequency suppressed carrier waves each having a single sideband 6 kc. wide. A high degree of reliability is provided at transmission speeds of 100 words per minute in Baudot code characters.

Such compact spacing of a large number of intelligence channels as above described has not hereotfore been feasible in systems employing this desirable "ratio squaring" method of diversity combining as above described, because of a tendency of the sharply tuned channel filters necessarily used for separating the intelligence channels to produce amplitude distortion which the AGC amplifiers are then unable to correct when operated at the lower audio frequencies. An object of the present invention is to provide novel means to overcome this difficulty.

Frequency division multiplex installations of the instant type require a separate, stable, and constant frequency shift source for the operation of each basic carrier channel. A further object of the present invention is to provide means to reduce the number of types of such tone genreators to a fraction of that formerly required.

In order to insure that inteligence signals in the several diversity channels can be added to produce maximum intelligibility after amplification and combining of the type described, it is necessary to provide means for equalizing the time delay of the several diversity channels, so that a transmission made simultaneously over several of them will arrive in the receiver at the point for addition of the signals, at the same time, regardless of the different signal delay times encountered in their several paths, insofar as possible.

One of the objects of this invention is to provide means for delaying the signals incoming over any of the associated channels of a group in a diversity telegraph signaling system, by an amount which is adjustable to produce within the signal combiner a substantial coincidence of diversity signals which were produced simultaneously, but delayed in transit for different times.

Another object of this invention is to provide for adjustment of the relative delay of plural diversity reception signals to effect substantial coincidence therebetween by the use of equipment embodying novel circuitry and operation to produce rapid, simple, and precise delay adjustment before combining the signals.

Still another object of the invention is to accomplish frequency diversity telegraph communication in a multichannel system wherein the reception means is substantially independent of differences in channel delay arising in the various elements of the system such as multiplexing equipment, radio equipment and interconnecting wire facilities.

An additional object is the provision of a diversity telegraph receiving system in which the ratio of the amplitudes of the associated diversity signals is maintained constant during amplification thereof by equally amplifying the signals, the amount of said amplification being determined by the strongest signal, such that the output of the strongest signal is maintained at a predetermined fixed level, for conditioning said signals to be passed through ratio squaring expanders for subsequent combination thereof by addition.

A further object is to provide means for attaining optimum noise suppression in diversity communication signals received at one ratio of amplitudes, by means of equipment for always recombining them at a substantially constant level in the square of that ratio.

Another object of the invention is to provide in a diversity communications system having multiplex channels utilizing the entire voice band during propagation, means to translate a low frequency portion thereof into higher frequencies in separate circuits, for increasing the efficiency of automatic gain controls operating therein.

Another object of the invention is to provide a multiplex diversity communications system having some of its multiplex channels in the lower audio range of frequencies during propagation, and having frequency conversion means for those channels to secure improved efficiency by the use of higher frequency keying, filtering, and diversity reception.

A still further object of the invention is to provide in a diversity communications system having means for the differential adjustment of path delay, a direct reading indicator of relative path delay.

In accordance with the foregoing, a specific example of the system described has been constructed, and embodies a terminal facility providing 16 frequency- shift, 100 word per minute telegraph channels starting at 425 cycles and continuing at 170 cycle intervals to 2975 cycles. Multiplexing equipment is included for simultaneous utilization of both 6 kc. sidebands of a radio facility for telegraph, telephone, or facsimile communication. The receiving terminal employs common control of the automatic gain control amplifiers in each of the associated diversity paths to effect the combining principles aforementioned. These amplifiers, having a common AGC control, always have equal gain, the gain being an inverse function of the signal having the higher received level. Thus, the ratio of levels of two incoming diversity signals is preserved at the amplifier outputs, with the stronger signal having an output level at a constant predetermined value. Amplitude squaring expanders having a loss in decibels which is an inverse function of the input level in decibels follow the automatic gain controls in each diversity path equipment. The amplitude ratio of diversity signals at the expander outputs thus follows the square of their input ratio as required by the theory. The signals so amplified are combined by adding the outputs of their separate discriminators in series aiding connection to a telegraph loop amplifier through post detection limiters.

In order to fully realize the theoretical advantage of the ratio squaring method of signal combining as above described, it is necessary to employ automatic gain controls which maintain the same relative gain in the separate diversity channels, within close limits over a wide range. Such controls, comprising a variolosser, an amplifier, and a low pass filter, are therefore constructed to compensate for the effects of a 45 decibel fading range. Additionally, the response time is required to be sufficiently short to remove the amplitude effects of noise as well as the amplitude modulation introduced by channel filters in the presence of keyed signals.

The bandwidth of the channel filters, and particularly of the receiving filter, is a major factor in determining the time constant of the AGC system. Filters having a desirably high discrimination against adjacent channels are inherently narrower than less rigorous filters and so introduce a greater modulation transient on encountering frequency-shift signals. This amplitude transient is in the form of damped oscillation having a frequency of approximately twice the maximum dotting rate, or about 80 cycles, and the AGC circuit must therefore be responsive with at least this speed in order to suppress such transient and is so constructed. In addition, the AGC system is constructed to operate without interfering with the performance of the lowest frequency telegraph channel at 425 cycles, and without displaying instability at low frequencies due to direct regeneration of AGC control circuit frequencies lying below the cutoff frequency of the low pass filter in the AGC control loop path. This latter requirement is met by causing the combination of low frequency cutoff characteristics in the fixed amplifier, and the high frequency cutoff characteristics of the low pass filter to provide a loop gain of less than unity for all frequencies, and particularly for low frequencies, having a phase shift of 180 degrees.

Such an arrangement is preferable to one in which it is attempted to maintain the variolossers of the automatic gain controls in a closely balanced condition throughout the required large fading range, because in the present state of the art it would be necessary to select its components for near perfect balance, while with the system as described, unselected components can be used. This construction, moreover, is effective in preventing subharmonic generation by the AGC at submultiples of the received carrier frequency, an action similar to that of a regenerative frequency divider, which occurs when the loop loss for a fractional carrier frequency is insufficient to prevent such frequency from appearing at the output of the low pass filter in an amount sufficient to be regenerated by interaction with the carrier in the modulator stage.

Modulation instability is also suppressed by the instant AGC circuit, whereby the amplitude modulation properly applied to the carrier by the AGC circuit as its normal function, and amplified by the fixed amplifier, is prevented from traversing the low pass filter in any amount sufficient to provide a substantial phase reversed regeneration component at the modulator such as would cause the modulation to be self-sustaining. Such effect is in this case prevented by providing a low pass filter having relatively small phase shift of the modulation so that only a small and well damped modulation transient arises upon frequency shift keying.

The variable loss section of the AGC amplifier is a two-stage balanced variolosser employing germanium diodes as variable elements. The variolosser as constructed has a linear loss in decibels relative to applied control voltage so that substantially uniform AGC sensitivity is realized over the fading range with corresponding uniformity of transient response. By the use of semiconducting germanium diodes, the gain characteristics of the AGC amplifiers are held to a closer tolerance than would be practical if vacuum tubes were used. This is especially desirable when operating the equipment in four or more channel diversity reception, in order to achieve the close tracking of the gains of the associated diversity AGC amplifiers over the fading range, as required to realize optimum circuit performance. If the maximum operating temperature expected to be encountered due to adverse ambient conditions, is excessive for germanium diodes, silicon junction diodes can be employed.

The amplitude-squaring expanders previously mentioned may use germanium or silicon diodes as the loss-controlling elements, in a circuit arranged to give a 2:1 ratio between the output and input decibel levels. Although the function of an expander is to magnify any variations occurring in its input, the response time of the present expander has been made long enough so that signalling transients and high-frequency cancellations between signal and noise will not be magnified, but only the effects of signal fading. The addition of the diversity signals is effected subsequent to detection by connecting the discriminator outputs in series aiding to operate a limiting amplifier whose output is thereby subject to 25 decibels of additional limiting.

Since it is important for diversity operation that output signals of the discriminators be added in proper time phase, in order not to reduce the tolerance of the system to fortuitous displacements resulting from selective fading or noise, an adjustable delay network has been provided in each receiving path so that systematic delay differences between paths to be combined may be equalized. A maximum delay of 6 to 7 milliseconds is realized by the bridge type phase shifter employed, and may readily be adjusted to the necessary value of delay for line-up purposes as follows: A repetitive dot transmission is applied to both diversity channels of a pair and the reception terminated in separate loops patched to a delay comparator. The comparator comprises a pair of balanced bridge arms connected to an integrating zero center D.C. meter circuit through a switching type detector operated in synchronism with the incoming loop reversals. If the dotting reversals on the two loops are received in exact time phase, the voltage across the bridge arms will be zero and the meter will read zero. If not received simultaneously, the synchronous detector causes the meter to indicate by the direction of its deflection which channel is lagging, and by its magnitude, the extent of delay. Random fluctuations due to fading or noise integrate to zero so that only systematic differences in delay are indicated. The adjustable delay network in the leading channel can then be set to reduce the meter reading to zero thus indicating that the simultaneous diversity signals applied to the series aiding discriminators as above explained are in proper phase relationship. Such delay adjustment is required to be made only when the system arrangement is set up or changed and not as a routine operation.

A clearer understanding of the objects and advantages of the invention may be gained from the following detailed description, taken in connection with the accompanying drawings showing an illustrative embodiment of the invention, in which:

Fig. 1 is a schematic representation of a portion of a diversity communications transmitting terminal;

Fig. 2 is a continued portion of Fig. 1;

Fig. 3 is a like representation of a receiving terminal so constructed;

Fig. 4 is a continuation of Fig. 3;

Fig. 5 is a wiring diagram of a portion of Fig. 4;

Fig. 6 is a graph of the control characteristic of a variolosser subassembly of Fig. 5;

Fig. 7 is a graph of the transfer characteristic of the subassembly of Fig. 6;

Fig. 8 is a graph of the transfer characteristic of an amplitude squaring expander, a component of Fig. 4; and

Fig. 9 is a wiring diagram of a differential delay indicator according to the present invention.

Fig. 10 are diagrams representing the voltages existing in different parts of the circuit of Fig. 9 plotted as a function of time.

Referring now to the drawings, in Fig. 1 are shown closed circuit jacks J1 and J2 into which are to be plugged appropriate telegraph keying devices such as teleprinters or tape-controlled transmitters which open and close a circuit in accordance with an information code representing a message to be transmitted, or data transmitters of other types for generating signals representing information to be transmitted. When single diversity transmission is adequate under existing conditions of external interference, the 3-pole double throw switch SW1–2 is thrown to position A, whereby jack J1 and its associated keyer, not shown, is connected to frequency-modulate a basic carrier channel represented by oscillator **1**, by applying ground return to the circuit of its loop battery **4**, and jack J2 with its associated keyer similarly operates to frequency-modulate another basic carrier channel represented by oscillator **2**, through its loop battery **6**. In cases when double diversity operation is desired, jack J2 is not connected and switch SW1–2 is thrown to position *b*, whereby signals from jack J1 are caused to modulate both of the basic carrier channels represented by oscillators **1** and **2** simultaneously. Frequency shift modulated A.F. signals from each oscillator are subsequently led through individual fixed gain amplifiers **7** and **8** and individually tuned isolating band pass filters **9** and **10** respectively, at which point the signals from oscillator **1** are combined by parallel connection with signals from other oscillators **11** comprising a group of oscillators operating on different audio frequencies spaced 170 cycles apart in the upper half of the voice frequency band.

It is to be understood that the oscillators **11** comprising the said group are individually connected to switches numbered **3–4** through **15–16** in a manner similar to that described for oscillators **1** and **2**, so that each oscillator of group **12** is used in a separate even-numbered keying loop or else switched into the loop of next lower number to duplicate the keying in that loop, according to the setting of diversity switches SW**3–4** through **15–16** for two or four channel diversity. An eight-fold replication of the paired loop and oscillator input circuit shown on the drawing is thus effected.

Leaving the aforementioned sending filters **9** and **10** and corresponding ones of other frequencies **15** and **16**, the outputs of the several signal originating channels are combined by simple additive superposition into two sets of signals which have the same audio frequencies, as indicated in the graphs of Fig. 1 shown appurtenant to the outputs of filters **9** and **10** respectively, which depict the locations of the sub-bands containing the audio frequency signals within the spectrum employed, reciprocal voltage 1/E being plotted against frequency *f* in a manner to produce curves comparable to customary filter characteristics. Signals depicted by the former graph, those originating in the odd-numbered keying loops and occupying frequencies in the band 1785 to 2975 cycles per second, proceed to output coupler **23** which comprises audio input and output transformers **24** and **26** respectively, together with suitable fixed attenuators **28** and **29**, together with fixed resistor **27** for impedance matching to promote maximum power transfer.

Signals shown by the latter graph as identical to those of the former graph in frequency contain the different intelligence of separate keying loops, which are connected respectively to switches **3–4** to **15–16** after the manner of the keying loop of jack J2, to the extent that said switches are thrown to position A for single diversity transmission. Such switches as are thrown to position B cause paired channels to carry the same intelligence from an odd-numbered keying loop such as that of J1 while the loop of the next higher even number, such as that of J2, is rendered idle when double diversity transmission is used. Signals originating in oscillator **2** are amplified in fixed gain amplifier **8** and traverse the band pass sending filter **10** tuned to their frequency.

Leaving band pass filter **10**, the signals from oscillator **2** are likewise combined with those from another and duplicate group of oscillators **12** which have been individually amplified in amplifiers **14** and isolated by sending filters **16**. The oscillators **12** associated with sending channels **4–6–8** . . . **16** are connected thereto or individually to their companion diversity channels **3–5–7** . . . **15** respectively according to the position of diversity switches **3–4**, **5–6** . . . **15–16** associated with each, as heretofore described.

Entering balanced modulator **31**, signals in the even numbered channels are heterodyned, or translated, to a higher frequency range by beating with a signal from a fixed oscillator **32** having a frequency of 9690 cycles per second. The resulting higher frequencies are separated from undesired modulation products in band pass filter **33** and enter balanced modulator **34** where they are heterodyned, or translated, to a position in the lower half of the voice frequency band by beating with oscillator **36**, operating at 6290 cycles per second, as indicated in the graph shown appurtenant to the output of filter **37**, wherein 2M designates the sub-group of frequencies containing channel **2**, located in the low frequency half of the voice frequency band, after transposition thereto by the sub-group modulator, as above described.

Low pass filter **37** removes undesired modulation products from the above described signals fed to it, and assists in isolating the direct path circuits of the odd numbered channels from those of the modulated path in the even numbered channels so that they can be combined in the output coupler **23** and, after setting of amplitude in the level-adjusting attenuator **38** and amplification in the fixed gain amplifier **39**, emerge as a spectrum of 16 signals occupying an entire voice frequency band, as indicated in the graph shown appurtenant to the output of amplifier **39**.

In Fig. 2, signals from the circuits of Fig. 1, received over a transmission line **50** enter the transmission line coupler **51** comprising a matching transformer **52** and a branching network **53** within the multiplexer **54**. A portion of the signal voltage, containing a voice band having two sub-groups of signal frequencies therein, is led through an input transformer **56** as indicated in the graph shown appurtenant to the output thereof, fixed attenuator **57**, and isolating band pass filter **58** in the direct path through the multiplexer. A second output of the said coupler passes through an input transformer **59** and an isolating low pass filter **61**. This signal, comprising the translated path through the multiplexer **54**, enters balanced modulator **62** where it is heterodyned by beating with signals at 6290 cycles per second from fixed oscillator **63** to produce a band of signal frequencies occupying one voice frequency bandwidth, but positioned one such bandwidth higher in frequency than the low frequency portion of the audio spectrum as indicated in the graph shown appurtenant to the output of the said modulator. These translated signals are separated from undesired modulation products and the equipment is isolated, by band pass filter **64**, and is then applied to the output of filter **58** aforesaid, combining with the same to fully modulate the audio spectrum to 6 kc., as shown in the graph shown appurtenant thereto. The combined modulation is passed through level adjusting attenuator **66** and fixed gain amplifier **67** to the output transformer **68** where its impedance level is matched to that of suitable wires or lines **69** applying it as modulation to the emission of a single sideband radio transmitter **70**, which can be arranged by convenient and conventional means to provide further frequency diversity by propagating simultaneously on plural radio frequencies, or from plural geographic locations, or on both such plural frequencies and from such plural locations, as the severity of interference conditions may require.

In Fig. 3 is shown a line **81** from a radio receiver **80** adapted to receive and demodulate radio frequency signals transmitted on a single frequency and thereby provide to the circuits of Fig. 3 modulation signals of the type previously described as generated by the equipment of Fig. 2. The line **81** is matched to following equipment by the transformer **82**, and is terminated with a suitable impedance network by conventional equalizer **83**. Signals therefrom are led through attenuator **84** for level adjustment and through fixed amplifier **85** for augmentation and isolation before entering a demultiplexer **86**. Entering demultiplexer **86**, the modulation signals are applied to an attenuator **91** for level adjustment of the demultiplexer input, and branch to enter low pass filter **94** in the direct path. Only the sub-band containing channel **1**, unaltered in frequency position during its transmission and therefore located as before in the upper half of the lower voice band, and the sub-band containing channel **2** modulated into a position in the lower half of the lower voice band before transmission, pass through the filter **92** as indicated in the graph shown appurtenant thereto to the level adjusting attenuator **93** for setting relative path gain and the fixed amplifier **94** for restoring amplitude lost in the network, and thence out of the demultiplexer in the direct path.

Leaving attenuator **91** in another branch, the received modulation enters band pass filter **101** in the translated path wherein only the sub-band of channel **1**, translated to a higher frequency voice band before transmission, and the sub-band of channel **2**, similarly translated, as indicated in the graph shown appurtenant thereto, emerge to enter the balanced modulator **102**. Signals from an oscillator having a fixed frequency of 6290 cycles per second enter the modulator **102** and beating with the series of signal frequencies lying between 3315 and 5865 cycles per second supplied by filter **101** provide signals occupying the lower voice band, as indicated in the graph shown appurtenant to the output of amplifier **106**, in the same order and frequency position as those arriving in the direct path, but having been transmitted while occupying a different portion of the audio spectrum.

The signals from filter **104** pass through attenuator **105** for level adjustment and through fixed gain amplifier **106** for reenforcement before leaving demultiplexer **86**. Signals leaving demultiplexer **86** by the direct path through amplifier **94** enter input coupler **111** of the subgroup demodulator **112** and branch to form a direct path therethrough, containing the signals of the sub-band of channel **1** in their original frequency position, and some irrelevant signals of lower frequency. In the modulated path forming the other branch from coupler **111**, the signals entering balanced modulator **113** are signals originating in channel **2**, modulated into the low frequency half of the lower voice frequency band, and are there heterodyned by beating with a signal of 6290 cycles per second supplied thereto by fixed oscillator **114**, removing them into the band 6715–7905 cycles per second, at which frequencies they traverse band pass filter **116** which removes undesired modulation products and the irrelevant signals of channel **1** lying without this band. Leaving filter **116**, the said signals enter balanced modulator **117** wherein they are heterodyned by beating with a signal of 9690 cycles per second supplied thereto by a fixed oscillator **118**, thus restoring them to the original modulation frequencies of the sub-band, namely 2975 cycles per second for channel **2**, and spaced frequencies downwardly to 1785 cycles per second for the remaining even numbered channels through **16** as indicated in the graph shown associated with amplifier **119**. These signals are applied to fixed gain amplifier **119** for restoration of losses encountered in the process above described and leave the sub-group demodulator by the modulated path.

Signals leaving demultiplexer **86** by the translated path are in a frequency position identical to those leaving by the direct path above described, and enter subgroup demodulator **121** which has identical construction and operation to that of **112** described, and produces direct and modulated path outputs identical thereto, as indicated in the graphs shown appurtenant to the upper and lower pairs of output terminals at the right of the subgroup demodulator **121**.

In Fig. 4 the signals from the direct path output of the subgroup demodulator **112** of Fig. 3 are applied to channel filter **151** which is a bandpass filter tuned to a frequency of 1785 cycles per second where separation of the signals in channel **1** occurs, as well as to other individual channel filters and following equipment identical to that about to be described, used for the separation and treatment of signals in each of the other odd numbered channels. Similar signals from the direct path output of subgroup demodulator 121 likewise are applied to another channel filter 152 and to individual channel filters and duplicate following equipment for each of the said other odd numbered channels. Modulated path signals from both of the aforesaid subgroup demodulators 112 and 121 are similarly applied to following equipment including channel filters, which duplicates that above described for demodulator direct path signals and which operates on signals in the even numbered channels. Numeral 153 designates such a channel filter and following equipment of channel 2, which is adapted for use in cooperation with channel 1, as later described.

Leaving channel filter 151, signals enter delay network 154 later described in detail, where they undergo a time delay adjustable for matching to equivalence with that of other associated diversity paths. From network 154, signals enter variolosser 155 which is a wide range linear modulator responsive to D.C. control signals supplied through low pass filter 156 from rectifier 157 to attenuate the received signals by up to 40 decibels before they enter fixed gain amplifier 158 for amplification to a limiting value as detected by a connection from the output thereof to the said rectifier 157. Operating alone, the components 155–158 act as an automatic gain control having unusual precision of tracking over a wide range, and when a stronger signal is received over the instant path than over the associated channel through filter 152, there function is to so limit the signal voltage output to a fixed value. By means of conductors 171 and 171′, however, the AGC voltage is made common to that of an identical equipment bearing primed numbers in the diversity channel.

If operating on the diversity signal which happens to be larger in its path at a given time, the AGC thus operates to maintain its output signal level constant. When signals in the associated diversity path are stronger, however, the consequent higher AGC voltage developed therein overrides the smaller voltage developed in the fading path and reduces the gain therein to a value equal in decibels to that in the AGC of the associated path.

Signals leaving amplifier 158 enter an amplitude-squaring expander 159 comprising a variolosser as before described and a rectifier 161 operating from the incoming signal to modulate the variolosser for producing a variolosser output proportional in magnitude to the square of its said signal input voltage. Fixed gain amplifier 162 restores the signals to a convenient level by adding thereto a constant number of decibels, whereby their ratio remains unaltered with respect to the diversity signals leaving identical amplifier 162′ after progressing through duplicate associated channel equipment as denoted by primed numbers on the drawing.

Leaving expander 159, signals enter discriminator 163 whose output in the direct path of channel 1 is connected in a series circuit with that of discriminator 163′ in the diversity path of channel 1 for summation of the demodulated signals. Diversity reception switch S′1–2 when thrown to position A returns the output of discriminator 163′ to ground for completing the said series circuit.

Post detection limiter 165 is operated by the summation signals above described from discriminator 163 to provide a uniform excitation signal to the telegraph loop amplifier 166 which itself supplies signal power at a suitably low impedance to operate teleprinters not shown but connected thereto, as Printer Loop 1 through jack 167.

Identical loop equipment 165″, 166″ and 167″ is similarly connected in channel 2 by the diversity reception switch S′1–2 in this position, each channel operating one loop. When diversity reception switch S′1–2 is thrown to position B for double diversity reception, discriminators 163 and 163′ are further placed in series with a similar pair of discriminators operating in series in the equipment of channel 2. Loop equipment 165″, 166″ and 167″ associated therewith is deenergized, and a common AGC line 171″ from the AGC amplifiers of channel 2 is connected to the lines 171 and 171′ of channel 1. By this means, gain to a constant output amplitude is applied only to the strongest of the signals in four diversity channels, signals in the remaining three channels being amplified only in accordance with their original ratio to the strongest signal because of the gain suppression caused by interconnection with the larger AGC voltage produced by the strongest signal. Series summation occurs in the four discriminators after signal ratio-squaring and the resulting signal is connected to activate a single printer loop. The result can be described qualitatively as operation of the printer from the best of four received signals, but with reception greatly improved by substantial contributions from the other signals in accordance with their quality.

In Fig. 5 is shown a wiring diagram of the circuit of one diversity path in one of the channels of Fig. 4. Both the associated path of the same channel, and all paths of all other channels contain duplicate equipment identically disposed. Signals from a sub-group demodulator such as 112 and 121 of Fig. 3 enter channel filter 201 tuned to a carrier channel frequency which in the illustrative embodiment is identical to that of its duplicate associated path. Said signals emerge in level adjusting potentiometer 202 connected to grid 203 of phase splitting vacuum tube 204 having a plate 205 supplied through resistor 206 with positive potential from an external source and biased by cathode resistor 207 having the same value as resistor 206. A resonant circuit comprising inductor 208 and capacitor 209 tuned to the channel mid-frequency applies a signal from cathode 211 of tube 204 to grid 212 of tube 213 which is delayed by an amount adjustable by potentiometer 214 connected to plate 205 of tube 204, acting through a blocking condenser 215 connected thereto and to said grid 212. The circuit described comprises a bridge type phase shifting network capable of supplying in the instant case a delay up to approximately 7 milliseconds. Space current at plate 216 of tube 213, supplied by an external source through resistor 217, is influenced by the potential of grid 212 with respect to cathode 218 and produces a bias voltage in resistor 219 connected thereto and bypassed by condenser 221. Amplified and delayed unbalanced signal output is removed through condenser 222 connected to plate 216 and is applied to automatic gain control 231. By means of the said potentiometer 214, delay of the telegraph signal encountered in the equipment can be lengthened, if required, by any amount needed to match that of the associated diversity signal paths. Similar equipment in the associated diversity path is adjusted, if necessary, to complement the delay thereof to effect a similar match, with the result that companion signals in the diversity paths arrive in phase at the discriminator outputs. It is because of this adjustment of diversity signals to substantial phase identity that their summation as later described can extract from them a summation signal having an intelligibility which is markedly superior to that in any of the diversity paths contributing to its production. A more detailed description of the procedure used to establish phase coherence between associated diversity paths will be later supplied in connection with the description of the delay comparator used in the procedure.

Entering automatic gain control 231 the said signals are applied to variolosser 232 which comprises input and output isolating transformers 233 and 234, series resistors 237, and semiconductor elements 236 connected in two bridge circuit configurations across the signal carrying wires whereby a direct current path through the rectifiers is established without the introduction of direct current into the signal circuit. Germanium and similar semiconductors such as 236 have a resistance which varies widely according to the forward voltage across them, and by providing a separate low impedance source of adjustable constant voltage, such as the low pass filter 238 connected thereto, the said bridge rectifier circuits are caused to assume any desired resistance under control of the voltage developed by the said filter circuit. Constituting also an A.C. load on the signal circuit, the said bridges and their load **246**, together with line series resistors **237**, thus comprise a widely variable balanced ladder attenuator for line signals. Fig. 6 is a graph of the characteristic of such a variolosser as above described, wherein it is seen that by the application of three-tenths of a volt of direct current to the diode bridges, a direct current determined by their forward resistance is caused to flow therethrough to produce a reduction in gain of about 43 decibels in the signals passing through the line. It is further evident that the relation therebetween is substantially linear. Both such wide range and linearity of response are necessary to the operation of the present invention and it has been found that by the use of semiconductor variolossers, they can be accomplished much more conveniently and reliably than would be possible by the use of vacuum tube operated automatic gain controls of the conventional kind. It is imperative also for the correct operation of the invention that the semiconductors in the variolossers of the automatic gain controls in all associated diversity paths be maintained at substantially the same operating temperature in order that their characteristics shall substantially coincide, and not differ due to their inherent relatively high temperature coefficient of resistance. Signal currents from variolosser **232** enter fixed gain amplifier **239** wherein a constant number of decibels of gain are restored to the signal. A portion of the output thereof is rectified for output level control in rectifier **241**, filtered in a low pass filter network comprising resistors **242** and condensers **243** of low pass filter **238**, and pass to the grid **244** of vacuum tube **245** therein. Space current in cathode follower vacuum tube **245** flows through cathode resistor **246** in accordance with the value of rectifier signal voltage thus applied to its grid, and the potential developed therein is applied to variolosser **232** as above described, to maintain the output of amplifier **239** at a fixed amount.

Fig. 7 is a graph showing the relationship between output and input signal levels, in decibels, of such an automatic gain control, from which it can be seen that an output varying less than one decibel can be obtained from an input which varies as much as forty decibels.

Automatic gain control **231**, in addition to maintaining a substantially constant output voltage in the transmission path in which it is located, as above described, is also required to reduce the gain therein to an amount not greater than that of any other associated diversity path carrying the same signals. This is accomplished by interconnection of all the said companion AGC's at the wires **247**, **248**, **249**, and **240**, respectively, whereby the highest control voltage as produced in wires **247** by the AGC having the strongest signal in its path, maintains the output thereof constant as aforesaid, while reducing the decibel gain ratio in all other companion path equipment to a value equal to its own because of the fact that the said higher AGC voltage causes all other diodes **248** of those so connected together to become nonconducting, placing all the tubes such as **245** thereof under control of said higher voltage. Wire **240** connects to a source of fixed positive bias voltage nearly equal to the voltage developed in resistor **246**, so that the difference therebetween, which is the control potential applied to the variolosser, can be changed by a relatively large percentage by means of a small change in space current of tube **245**. It is convenient to interconnect all wires such as **240** and also all cathode wires such as **248** in the associated diversity channels, for although they are intended to perform identically under control of the voltage in wire **247**, individual variations in performance can arise due to the unusually wide range of operation required. Interconnection of all of the said wires is made in the same manner, as shown in Fig. 4 where **171** and **171'** represent a permanent interconnection of one such wire between two paths which, in the present equipment, are always associated, and the wire at the junction therebetween together with the wire **171''** represent a connection therefrom to another pair of diversity paths which is closed by a switch such as **S'1–2** when the same telegraph signals are in all the said paths for double-diversity reception.

Entering amplitude-squaring expander **251** from automatic gain control **231**, signals are applied through condenser **250** to grid **252** biased by resistor **254** of triode **253** having a cathode circuit comprising cathode bias resistor **255** and output resistors **257** and **258**. Signal current voltage drop in resistors **257** and **258** is applied through condenser **256** to the input winding of transformer **259**. Signal output from a high impedance winding of the transformer is rectified in diodes **264** and applied in series with a biasing voltage drop developed in resistor **258** to provide a D.C. control current filtered in condensers **263** and resistors **262** for application to the variolosser comprising a low impedance winding of transformer **259** and the silicon diodes **261**. Resistance of the said diodes **261** is strongly influenced by the flow of current through them and presence of a signal of large amplitude in the signal circuit causes sufficient flow of current through the diodes **264** to alter the resistance of diodes **261** markedly and thus to influence the level of the signals passing therethrough and applied to output transformer **262**. Diodes **261** are employed in a constant current circuit, by which is meant that the circuit resistances thereof are so designed as to deprive resistance changes in the said diodes of any substantial control over the flow of direct current therethrough. In this mode of operation, the characteristic of the circuit is that of signal squaring. Resistor **268** is connected across the secondary winding of transformer **259** to assist in matching the impedance of diodes **261** to that of the signal path. A fixed gain amplifier **265** is connected to the output of transformer **262** for supplying to the signals therefrom a constant number of decibels of gain.

Fig. 8 is a graph showing the relationship between the output and input signal levels, in decibels, of such an amplitude squaring expander. It is to be noted that the output scale is compressed in relation to the input scale by a factor of two, and that since the decibel notation employed is a logarithmic measure, the substantially straight line characteristic of the expander as shown represents a squaring within the expander, of the amplitude of applied signals. Such squaring is necessary for optimum performance of the instant invention, and although expansion by other than the square of the signal voltage can be employed, such methods have increased usefulness according to the closeness of their approach to such squaring.

Signals leaving expander **251** enter conventional discriminator **163** for recovery of telegraph signals, and emerge therefrom in series connected circuit through wires **266** to a corresponding point in the circuit of identical equipment in the diversity path permanently associated therewith, of which Fig. 5 is typical. Wires **267**, also in the series circuit, connect discriminator **163** to a diversity receiption switch such as **S'1–2** of Fig. 4 for further series connection of discriminators in the said two permanently associated paths with similar discriminators in another pair of paths, when it is desired to provide for the reception of double diversity signals occupying four paths in two channels.

Post detection limiter **165** is connected to and operated by signals in discriminator **163** and such other discriminators as may be connected to it at a given time as above described, to provide telegraph signal excitation of uniform character to low impedance loop amplifier **166** having an output jack **167** for connection to a telegraph printer loop not shown on the drawing.

In Fig. 9 is shown the wiring diagram of the circuit of a comparator for measuring relative delay between diversity signal paths. The comparator consists of a pair of equal bridge arms comprising resistors **301** and **303** and resistors **302** and **304** respectively, bridged across a signal input obtained by the connection with patch cords (not shown) of jacks **322** and **323** to jacks **167** and **167''** of Fig. 4. The junction of said bridge arms is grounded and a reduced portion of the balanced voltage thereacross applied to junctions **326** and **327**. A zero center D.C. milliammeter **305** connected in an integrating circuit comprising resistors **306**, **307** and condenser **308** is connected across the said junctions through a reversing type balanced diode switch comprising diodes **309**, **310**, **311**, **312** and resistors **315**, **316**, **317**, and **318**. The operation of the circuit can be better understood by reference to the diagrams of Fig. 10 wherein the voltage existing in different parts of the circuit is plotted as a function of time. As a typical case the potential to ground appearing in each of the jacks **322** and **323** after connection to the corresponding jacks **167** and **167''** of Fig. 4 by means of patch cords are illustrated at A and B in Fig. 10. These signals arise from the reception of unbiased dot signals transmitted for testing purposes through the separate signal channels of plural diversity paths. Two channels, each of which has two diversity paths, are used for this transmission in the instant procedure, although the number of signal paths which can be equalized by this means can be as large as desired. It will be noted, in the example given, that the signals indicated by wave form B have a greater delay than those represented by wave form A. These two wave forms, partially differentiated respectively by condensers **319** and **321**, are combined at the junction **324** and produce a potential to ground having the wave form shown in Fig. 10D. A wave form which is the difference between A and B exists between jacks **322** and **323**, and at junctions **326** and **327**, as shown at C.

Circuit impedances are so designed that a relatively large current flows to ground from the junction **324** either through diodes **310** and **311**, or through diodes **309** and **312** depending upon the polarity of **324** as shown in D, but since these circuits are balanced with respect to meter **305**, this produces no flow of current therein. During said current flow in diodes **309** and **312**, however, they are capable of conducting any relatively smaller flow of current between junctions **325** and **327** through the circuit of meter **305**, in either direction, to produce a deflection of the meter. When said large current flows to ground in the opposite direction through diodes **310** and **311**, the meter is thereby connected to junctions **326** and **327** through a reversing switch type of connection as shown, the reversals thereof being synchronous with the reversals of the potential C applied to meter **305**. Since the potential C being rectified for application to the meter **305** undergoes phase reversal whenever that signal of A or B which leads in phase changes to lagging, while the potential of D, which operates the synchronous reversing switch to provide said rectification as described, remains unaffected by such change, the direction of the rectified meter current, shown at E, indicates which wave of A or B is first arriving, and the average magnitude thereof, as shown by the deflection of the meter **305** indicates the time difference between times of arrival of corresponding points on the two waves, which is the relative delay.

The indicating needle of the instrument swings either to the right or to the left depending upon which of the channel paths contains the greater delay, and gives an indication as to which of the channels requires added delay inserted to equalize the delay between the two channels being compared. The function of the integrating network containing resistors **306**, **307** and condenser **308** is to suppress random variations of delay arising in the radio frequency transmission paths of the diversity signals such as multi-path transmission effects so that only indications of systematic equipment delays, that is, delay differences which are inherent in the filters, transformers and other portions of the equipment, are indicated.

The channel in which the least delay occurs is then adjusted by means of the delay **154** in Fig. 4 until the meter **305** shows a zero reading. The particular system presently described is adapted for either two or four path diversity operation and therefore provides a separate printer loop output circuit only for each associated pair of diversity paths. Four diversity paths are adjusted to have equal delay since either single or double diversity reception may be required, and inasmuch as the measuring instrument can equalize only two paths at a time, each of which is in a different carrier channel because of the need for using an independent printer loop in each path, the procedure to be followed in equalizing the delay of four channels, although rapid and straightforward in execution, is explained as follows:

Jacks **322** and **323** are connected by means of patch cords with printer loop circuit jacks such as **167** and **167''** of Fig. 4 in two separate channels. As a first step, one of the diversity paths such as A in each of the channels such as **1** and **2** is activated by closing a switch such as **401** in each channel, all other such switches remaining open. Diversity dot signals as above described are received in the two active paths, and in general cause a comparator meter deflection because of unequal signal delay in the equipment. From an initial setting of minimum delay, one of the two active delay adjusting circuits such as **154** is advanced to add sufficient delay in its path to reduce the meter reading to zero. That one is advanced which is indicated by the direction of the meter deflection. By this means path **1A** is equalized with **2A**. As a second step switches **401** are opened and **401'** closed in each channel and the other diversity paths B thereof are equalized by a similar procedure. As a third step, path **1A** is equalized with path **2B** by having only switch **401** closed in channel **1** and **401'** closed in channel **2**. This requires insertion of delay in one path which may already have had some delay inserted in step first or second, but such procedure is not redundant, and is effective in bringing both paths to a single and final value of equal delay. Finally, as a fourth step, path **1B** is equalized with **2A**, having only switches **A401'** and **B401** closed, again by adding delay to the less delayed path. In no case is delay removed from a path during adjustment, for the following reason: since one of the paths of step fourth had already by step one or two as circumstances required, been made equal in delay to that path of step third having the greater delay, the adjustment is completed by step fourth, and all four paths are thereby made equal in delay, as is necessary for optimum intelligibility of the signals in the single printer loop when they are combined to provide a summation signal from four separate diversity paths. It is to be observed that by this procedure, there remains one of the four paths, that which is most delayed, in which no additional delay has been inserted. This is desirable in order to conserve the delaying capacity of the delay circuits by operating them at the lowest possible setting, both to insure that their range will not uselessly be exceeded in the equalization of four-path transmissions, and especially to provide for equalization of more than four paths, when transmission conditions make it desirable to do so. Such further equalization of a larger number of paths can be accomplished by successive reapplication thereto of the procedure as explained.

While single diversity is usually sufficient for long distance short wave communications when transmission conditions are normal, there are often periods when severe multi-path phenomena or interference conditions increase the message error rate to an unacceptable value. Under such conditions it has been observed that the error rate can be reduced by a ratio of as much as 10 to 1 by switching to double or four path diversity operation. As a consequence of this it is clear that the period of usability of a given radio frequency channel which is normally limited can be significantly extended, and that an otherwise unsatisfactory circuit can be rendered operable by use of the instant invention.

It is to be understood that the number of separate diversity paths which can be so combined is not limited to a maximum of the four described, but by proper circuit design can be extended to any desired number, to produce a further improvement in circuit performance. A corresponding decrease in the total message handling capacity of the telegraph terminal system is of course engendered by each such multiplication of the diversity paths.

The foregoing disclosure contemplates a specific embodiment of the preferred form of the present invention. Obviously, numerous alternative arrangements and expedients will occur to those skilled in the art, which nevertheless lie within the spirit of the inventive concept here disclosed. It is therefore intended that this invention shall be limited only by the scope of the appended claims.

What is claimed is:

1. In a diversity telegraph system, a basic carrier channel and means for frequency-modulating said carrier channel in accordance with intelligence signals, means including a radio transmitter for propagating radio waves modulated in accordance with said intelligence signals of the modulated carrier channel and radio receiving means for receiving said signals over a plurality of associated diversity channel signal paths, said receiving means having associated diversity channel signal output paths and manually adjustable delay means in each of said paths for equalizing any signal delay differences between said associated channel signal paths, automatic gain controls respectively in said associated output paths and interconnected for operation for equal gain and having a predetermined limiting amplitude of output, signal ratio-squaring expanders respectively responsive to the outputs of said automatic gain controls, discriminators respectively connected to the outputs of said signal expanders and interconnected to derive a common signal from said paths of the basic carrier channel, and a post-detection limiting means responsive to said derived signals to recreate the transmitted intelligence signals.

2. In a diversity telegraph system, a basic carrier channel and means for frequency-modulating said carrier channel in accordance with intelligence signals, means including a radio transmitter for propagating radio waves of different frequencies each modulated in accordance with said intelligence signals of the modulated carrier channel and radio receiving means for receiving said signals over a plurality of associated diversity channel signal paths, said receiving means having associated diversity channel signal output paths and manually adjustable delay means in each of said paths for equalizing any signal delay differences between said associated channel signal paths, automatic gain controls respectively in said associated output paths and interconnected for operation for equal gain and having a predetermined limiting amplitude of output, signal ratio-squaring expanders respectively responsive to the outputs of said automatic gain controls, discriminators respectively connected to the outputs of said signal expanders and interconnected to derive a common signal from said paths of the basic carrier channel, and a post-detection limiting means responsive to said derived signals to recreate the transmitted intelligence signals.

3. In a diversity telegraph system, means for forming a first group of spaced basic carrier channels, means for selectively modulating the carrier frequency of at least one of said basic channels in accordance with intelligence signals, means for producing from said first group of carrier channels a second channel group lying in a different frequency range to provide diversity transmission by means of direct and diversity paths of different frequencies for each basic carrier channel, means for propagating radio waves modulated by said channel groups and a radio receiver responsive thereto, output paths for each of the spaced basic carrier channels of said direct and diversity groups, manually adjustable delay means in each of said output paths for equalizing any signal delay differences between the corresponding basic carrier channels of said direct and diversity groups which are modulated by the same intelligence signals, automatic gain controls respectively in said output paths for each carrier channel, the corresponding automatic gain controls being interconnected for operation at equal gain and having a predetermined limiting amplitude of output, signal ratio-squaring expanders respectively responsive to the outputs of said automatic gain controls, discriminators respectively connected to the outputs of said signal expanders and connected for series addition of direct and diversity signals of each said corresponding basic carrier channel to produce a summation signal, and a post-detection limiting means responsive to each of said summation signals to recreate the transmitted intelligence signals.

4. In a diversity telegraph system, means for forming a first group of spaced basic carrier channels, means for selectively modulating the carrier frequency of at least one of said basic channels in accordance with intelligence signals, means for producing from said first group of carrier channels a second channel group lying in a different frequency range to provide diversity transmission by means of direct and diversity paths of different frequencies for each basic carrier channel, means for propagating radio waves modulated by said channel groups and a radio receiver responsive thereto, means for translating said second group of carrier channels back into the frequency range of said first group, output paths for each of the spaced basic carrier channels of said direct and diversity groups, manually adjustable delay means in each of said output paths for equalizing any signal delay differences between the corresponding basic carrier channels of said direct and diversity groups which are modulated by the same intelligence signals, automatic gain controls respectively in said output paths for each carrier channel, the corresponding automatic gain controls being interconnected for operation at equal gain and having a predetermined limiting amplitude of output, signal ratio-squaring expanders respectively responsive to outputs of said automatic gain controls, discriminators respectively connected to the outputs of said signal expanders and connected for series addition of direct and diversity signals of each said corresponding basic carrier channel to produce a summation signal, and a post-detection limiting means responsive to each of said summation signals to recreate the transmitted intelligence signals.

5. In a diversity telegraph system, means for forming first and second identical sub-groups of spaced basic carrier channels lying in the same frequency range, means for selectively modulating the carrier frequencies of at least two associated ones of said basic channels respectively in said sub-groups in accordance with the same intelligence signals, means for translating one of said sub-groups into a different frequency range, means for producing from said first and second sub-groups of carrier channels third and fourth sub-groups lying in a frequency range different from that of the first and second sub-groups to provide diversity transmission by means of at least four diversity paths of different frequencies, means for propagating radio waves modulated by said different frequencies and a radio receiver responsive thereto, means for translating said third and fourth sub-groups back into the frequency range of said first and second sub-groups, means for translating said sub-groups relative to each other to position all of them in the same frequency

range, output paths for each of said associated basic carrier channels of each of said sub-groups, manually adjustable delay means in each of said output paths for equalizing any signal delay differences between the associated basic carrier channels of said sub-groups which are modulated by the same intelligence signals, automatic gain controls respectively in said output paths for each of said carrier channels, the associated automatic gain controls being interconnected for operation at equal gain and having a predetermined limiting amplitude of output, signal ratio-squaring expanders respectively responsive to the outputs of said automatic gain controls, discriminators respectively connected to the outputs of said signal expanders and connected for series addition of the diversity reception signals of the associated basic carrier channels to produce a summation signal, and a post-detection limiting means responsive to each of said summation signals to recreate the transmitted intelligence signals.

6. A system according to claim 5, including means in the radio receiver for translating said first, second, third and fourth sub-groups relative to each other to position all of them in the same frequency range.

7. In a diversity telegraph system having at least one basic carrier channel and means for producing frequency shift modulation of said carrier channel in accordance with intelligence signals, means including a radio transmitter for propagating radio waves modulated in accordance with said carrier channel and radio receiving means for receiving said signals over a plurality of associated diversity channel signal paths, said receiving means having associated diversity channel signal output paths and manually adjustable delay means in each of said paths for equalizing any signal delay differences between said associated channel signal paths, automatic gain control circuits respectively in said associated output paths, means interconnecting said gain control circuits for operation at equal gain and having a predetermined limiting amplitude of output, said automatic gain control circuits each having an amplifier at its output end, each gain control circuit comprising a variable attenuator including semi-conductor diodes in a bridge network in the corresponding output path, the attenuation thereof being variably controlled by a direct current control voltage applied to said diodes from said means interconnecting the gain control circuits to cause all of the signals at any instant in the associated diversity paths to be amplified to substantially the same extent to preserve the ratio of the amplitudes of the signals at the outputs of the automatic gain control amplifiers, signal ratio-squaring expanders respectively responsive to the outputs of said automatic gain control amplifiers, discriminators respectively connected to the outputs of said signal expanders and interconnected to derive a common signal from said paths of the basic carrier channel to produce a derived signal, and a post-detection limiting means responsive to each of said derived signals to recreate the transmitted intelligence signals.

8. A system according to claim 7, in which said variable attenuator includes a diode bridge network connected in shunt across said corresponding signal output path.

9. A system according to claim 7, in which said variable attenuator includes a plurality of diode bridge networks each connected in shunt across said corresponding signal output path and coacting to increase the variable range of decibel loss obtainable thereby.

10. A system according to claim 7, in which said variable attenuator comprises fixed resistor branches in series with said signal output path and variable branches comprising diode bridge networks in shunt with said signal output path.

11. A system according to claim 7, including means for causing the control voltage applied to the semi-conductor diodes in any of said automatic gain control circuits in a diversity path to be increased to a value to maintain substantially constant signal output from its output amplifier whenever the amplitude of the signal in said path is larger than that in any associated diversity path.

12. A system according to claim 11, including a rectifier connected to the output of said output amplifier, means including a diode switch connected to the output of said rectifier and having its output interconnected with a corresponding diode switch in each associated diversity path for applying rectified signal output voltage to the interconnection between said diodes only when the amplitude of the signal output from said output amplifier is larger than that from the output amplifier in any associated diversity path to thereby increase said control voltage applied to the semiconductor diodes of the attenuator.

13. A system according to claim 12, including a low pass filter connected to the output of said diode switch, a cathode follower connected to the output of said filter, means for applying a fixed direct current biasing voltage to said semi-conductor diodes, and connections for causing said cathode follower to apply to said semi-conductor diodes a variable control voltage sufficiently higher than that of the biasing voltage to effect control of said semi-conductor diodes, said last-named connections also extending to the semi-conductor diodes in the attenuator of each associated signal output path.

14. In a diversity telegraph system, a basic carrier channel and means for frequency-modulating said carrier channel in accordance with intelligence signals, means including a radio transmitter for propagating radio waves modulated in accordance with said intelligence signals of the modulated carrier channel and radio receiving means for receiving said signals over a plurality of associated diversity channel signal paths, said receiving means having associated diversity channel signal output paths and manually adjustable delay means in each of said paths for equalizing systematic signal delay differences between said associated channel signal paths, automatic gain controls respectively in said associated output paths interconnected for operation for equal gain and having a predetermined limiting amplitude of output, signal amplitude-squaring expanders respectively responsive to the outputs of said automatic gain controls, each said signal expander comprising an input transformer, an output transformer, a pair of semi-conductor diodes connected between windings of said transformers, said diodes being poled in the same direction with respect to the signal path through the expander, a rectifier circuit for rectifying a portion of the incoming signal to the expander to produce a control current, the resistance of said rectifier circuit being relatively high with respect to the resistance of said semi-conductor diodes, conductors for applying said control current to center taps of windings on said input and output transformers for causing balanced control current to flow through said diodes, and a fixed-gain amplifier connected to an output winding of said output transformer, discriminators respectively connected to the outputs of said signal expanders and connected for series addition of the signals of said paths of the basic carrier channel to produce a summation signal, and a post-detection limiting means responsive to each of said summation signals to recreate the transmitted intelligence signals.

15. In a frequency shift radio telegraph communication system wherein diversity reception signals in associated paths are amplified proportionately to their received amplitudes and expanded according to the square thereof before summation by a combiner into a single signal, adjustable signal path delay means in each diversity path for effecting system delay equalization, and indicator means having an input circuit adapted for connection to the output circuit of pairs of said diversity paths for comparing the delay differences between said paths, said input circuit including a pair of resistive bridge arms balanced to ground, a pair of diode switches poled in

one direction and connecting balanced taps on said bridge arms to a pair of conductors in an indicating circuit, a pair of diode switches poled in the opposite direction and reversely connecting said taps to said pair of conductors, a pair of condensers of equal capacity connected in series across said input circuit, a pair of resistors of the same value connected in series across said pair of conductors in the indicating circuit, a connection between the common connection of said condensers and the common connection of said resistors for applying a switching voltage to said diode switches in response to signal reversals of the signals in the path having the least delay, a deflection meter having a mid-scale zero position and an integrating network connected across said meter for causing deflection of the meter, indicating relative path delay and in a direction depending upon which of said paths has the least delay.

16. In a diversity telegraph signaling system in which a plurality of spaced basic carrier channels occupies a given voice band in the lower frequency portion of the voice frequency range, means for forming first and second identical sub-groups of basic carrier channels, each of said sub-groups initially occupying the higher frequency portion of said given voice band, means for selectively modulating the carrier frequency of at least one of said basic channels in accordance with intelligence signals, means to translate the basic carrier channels of the first said sub-group to a range lower in frequency than said second sub-group thereby to form a first channel group having upper and lower portions in adjacent frequency ranges which collectively substantially occupies said given voice band, a multiplexer circuit for producing from said first channel group a second channel group lying in an adjacent voice band of higher frequency range than said voice band to provide diversity transmission by means of direct and diversity paths of different frequencies for each basic carrier channel, means for propagating radio waves modulated by said channel groups and a radio receiver responsive thereto, apparatus controlled thereby comprising a demultiplexer circuit to translate the channel signals of said second channel group back into the frequency range of said first channel group, carrier channel group filters respectively in said direct and diversity paths, means to translate said lower portion of said first channel group and said translated second channel group to the same range of frequencies occupied by the upper portion thereof to form first and second direct sub-groups of spaced basic carrier channels in the same frequency range and corresponding first and second diversity sub-groups of spaced basic carrier channels in said same frequency range, output paths for each of the spaced basic carrier channels of said direct and diversity sub-groups, manually adjustable delay means in each of said output paths for equalizing any signal delay differences between the corresponding basic carrier channels of said direct and diversity sub-groups which are modulated by the same intelligence signals, automatic gain controls respectively in said output paths for each carrier channel, the corresponding automatic gain controls being interconnected for operation at equal gain and having a predetermined limiting amplitude of output, signal ratio-squaring expanders respectively responsive to the outputs of said automatic gain controls, discriminators respectively connected to the outputs of said signal expanders and connected for series addition of direct and diversity signals of each said corresponding basic carrier channel to produce a summation signal, and a post-detection limiting means responsive to each of said summation signals to recreate the transmitted intelligence signals.

17. In a diversity telegraph signaling system in which a plurality of spaced basic carrier channels occupies a given voice band of substantially about three kilocycles width in the lower frequency portion of the voice frequency range, means for forming first and second identical sub-groups of basic carrier channels, each of said sub-groups initially occupying the higher frequency portion of said given voice band in the frequency range of substantially about 1700 to 3000 cycles per second, means for selectively modulating the carrier frequency of at least one of said basic channels in accordance with intelligence signals, means to translate the basic carrier channels of the first said sub-group to a frequency range of substantially about 425 to 1600 cycles per second thereby to form a first channel group having upper and lower portions in adjacent frequency ranges which collectively substantially occupies said given voice band, a multiplexer circuit for producing from said first channel group a second channel group lying in an adjacent voice band in the frequency range of substantially about 3000 to 5900 cycles per second to provide diversity transmission by means of direct and diversity paths of different frequencies for each basic carrier channel, means for propagating radio waves modulated by said channel groups and a radio receiver responsive thereto, apparatus controlled thereby comprising a demultiplexer circuit to translate the channel signals of said second channel group back into the frequency range of said first channel group, carrier channel group filters respectively in said direct and diversity paths, means to translate said lower portion of said first channel group and said translated second channel group to the same range of frequencies occupied by the upper portion thereof to form first and second direct sub-groups of spaced basic carrier channels having the same frequencies, in the range of substantially about 1700 to 3000 cycles per second and corresponding first and second diversity sub-groups of spaced basic carrier channels also having the same said frequencies in the last said frequency range, output paths for each of the spaced basic carrier channels of said direct and diversity sub-groups, manually adjustable delay means in each of said output paths for equalizing any signal delay differences between the corresponding basic carrier channels of said direct and diversity sub-groups which are modulated by the same intelligence signals, automatic gain controls respectively in said output path for each carrier channel, the corresponding automatic gain controls being interconnected for operation at equal gain and having a predetermined limiting amplitude of output, signal ratio-squaring expanders respectively responsive to the outputs of said automatic gain controls, discriminators respectively connected to the outputs of said signal expanders and connected for series addition of direct and diversity signals of each said corresponding basic carrier channel to produce a summation signal, and a post-detection limiting means responsive to each of said summation signals to recreate the transmitted intelligence signals.

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