

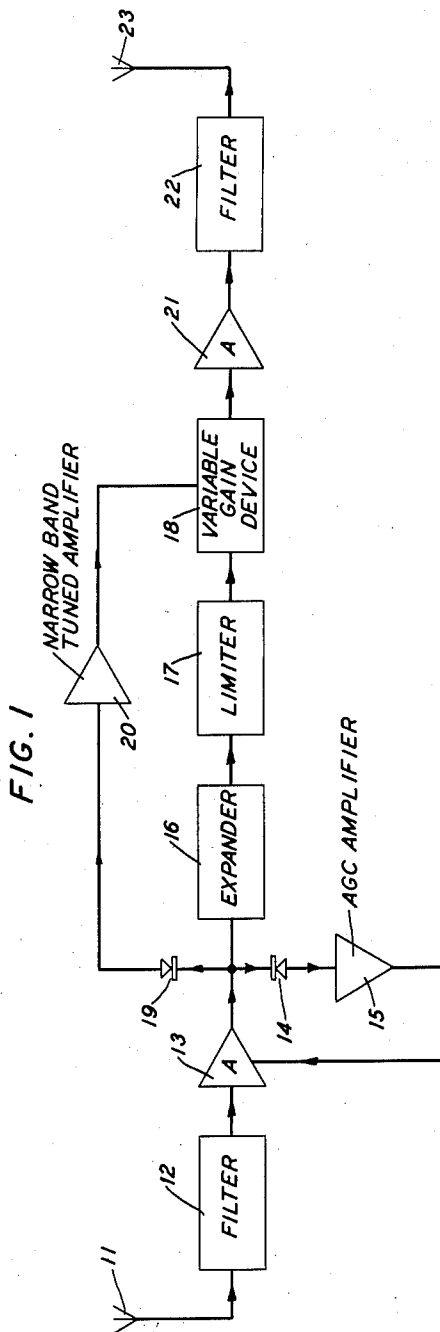
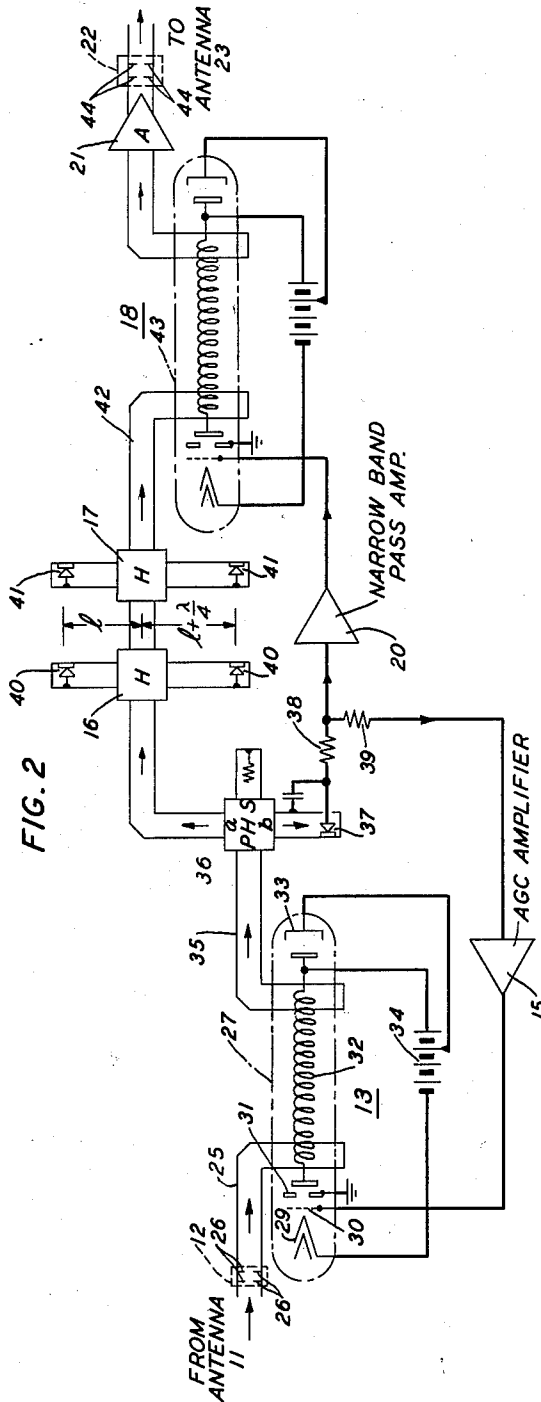
Feb. 21, 1956

J. R. PIERCE
PULSE REPEATER

2,735,933

Filed Sept. 9, 1950

3 Sheets-Sheet 1



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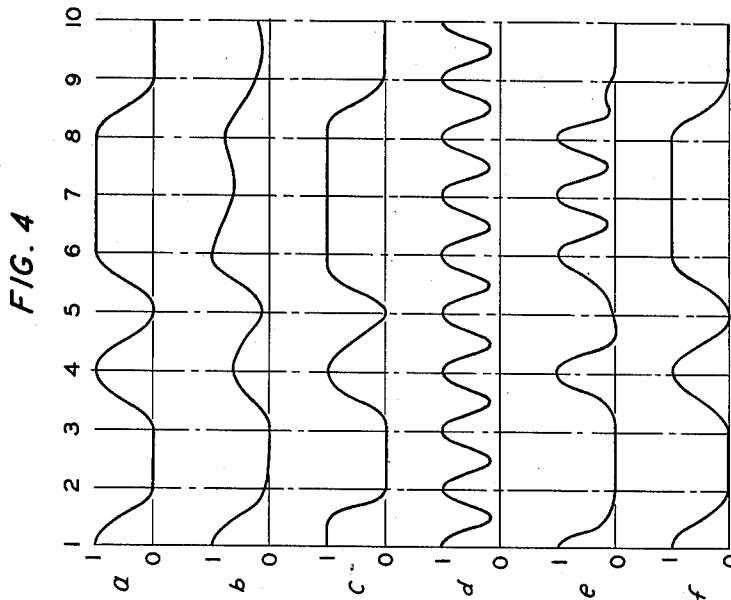
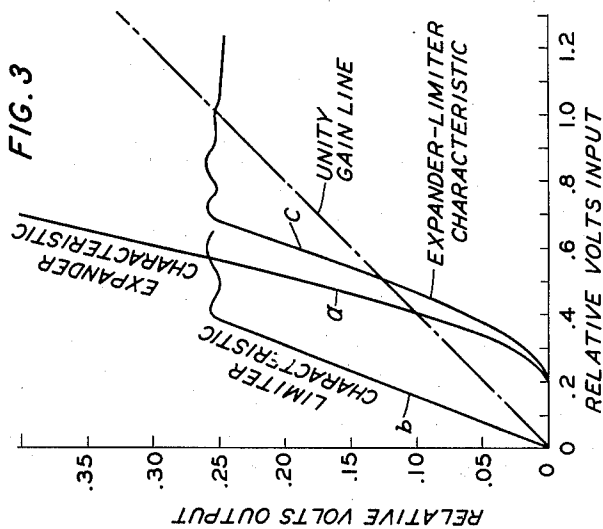
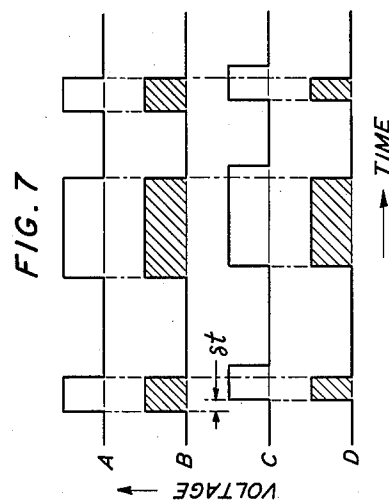
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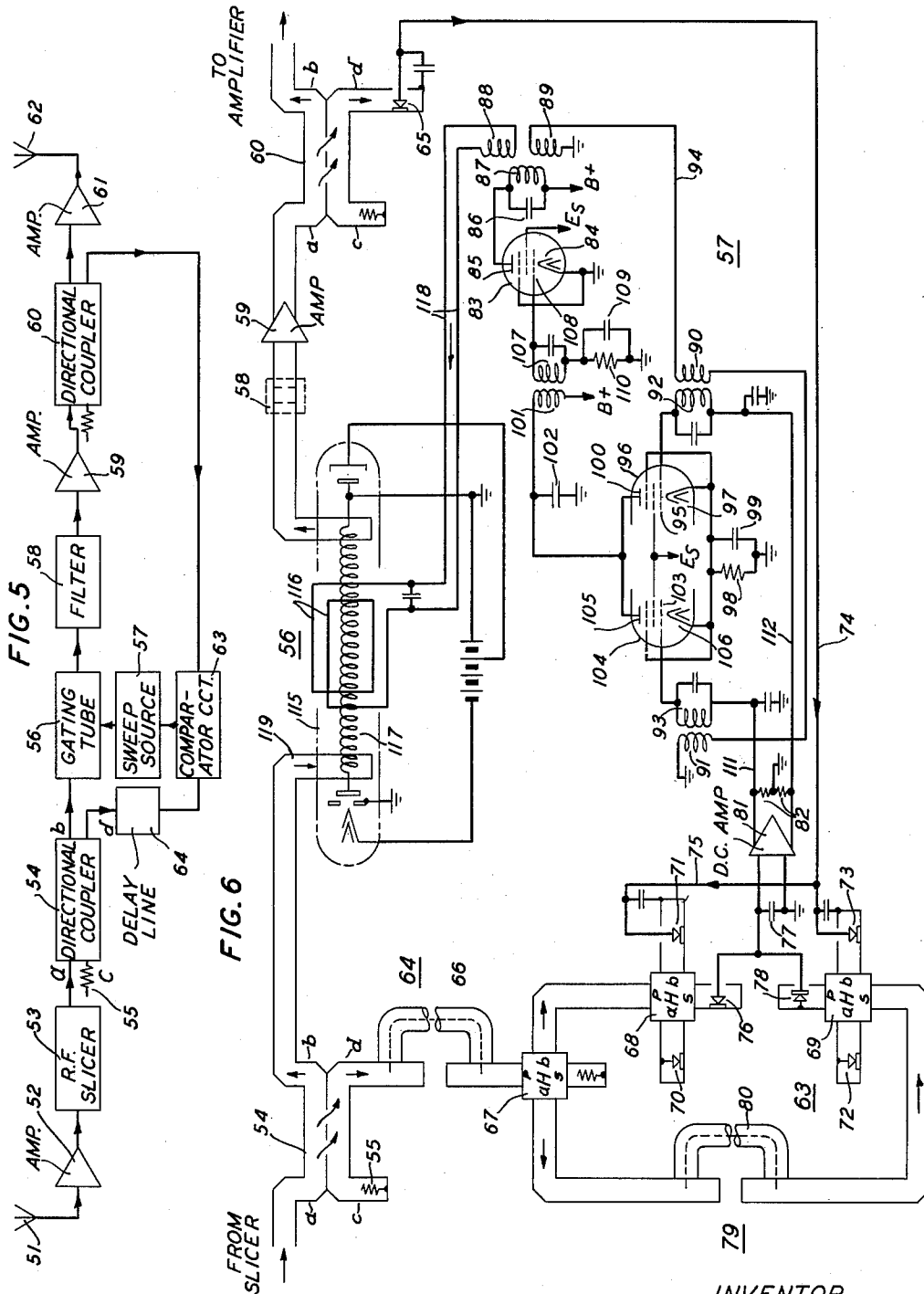
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3 Sheets-Sheet 3



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2,735,933

PULSE REPEATER

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Application September 9, 1950, Serial No. 184,646

15 Claims. (Cl. 250—15)

This invention relates to microwave pulse transmission systems and more particularly to microwave pulse repeaters.

The principal object of this invention is a regenerative repeater for relaying microwave pulses in a radio relay system where repeater spacing is relatively small, for example, on the order of a few miles. A related object of the invention is a pulse repeater which is simple of design and which is sufficiently inexpensive to warrant close repeater spacing.

Another object of the invention is to relay extremely short pulses at microwave frequencies and to partially reshape and retime the pulses being relayed.

A further object of the invention is to amplify, reshape and retime microwave pulses without reducing the pulses to an intermediate frequency.

A more specific object of the invention is a relatively inexpensive, incompletely regenerative pulse repeater for use in a radio relay system at wavelengths on the order of one and one-half centimeters or less and which is capable of handling over a thousand broad-band channels multiplexed in time division.

Another object of the invention is to regenerate a broad-band radio frequency signal consisting of very short pulses without requiring broad-band auxiliary amplifiers.

A great portion of the initial cost and carrying charges of a microwave pulse communication system of the radio relay type lies in the repeater stations. In present known systems the cost per mile is reduced by keeping the spacing between repeaters as large as possible, for example, on the order of from 35 to 50 miles. This, however, requires that the wavelength be kept greater than about 5 centimeters to avoid excessive rain attenuation; longer wavelengths in turn require larger antennas. Greater antenna spacings also require obstruction clearance locations for the repeaters due to the line of sight nature of microwave propagation. This means either very tall and expensive towers or hilltop sites which require both expensive site acquisition and expensive road construction and maintenance.

It may therefore be seen that if the cost of the repeater stations can be made low enough to permit closer spacings several advantages will result. For example, shorter wavelengths may be used in spite of rain attenuation since this type of attenuation is proportional to distance. Also, with shorter spacings and wavelengths, antennas may be smaller and obstruction clearances may be less, even over flat terrain. Further, roadside repeater sites and smaller and less expensive tower structures become permissible.

Complete regeneration, that is, accurate reshaping and retiming of the transmitted pulses, has been proposed in the past. However, in a radio relay system it is unlikely that deep fading will occur simultaneously on any two adjacent links. The present invention therefore makes use of a repeater which is incompletely regenerative making it extremely simple of design and hence relatively inexpensive. In an illustrative repeater embodying principles of the invention and described below in detail the

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received pulses are partially reshaped by an expander which discriminates in favor of the higher amplitudes tending to reduce the lower noise signals to zero and by a limiter which establishes the peak pulse amplitude.

Partial retiming is effected by a variable gain device whose gain is controlled by a sinusoidally varying voltage of the pulse repetition frequency which is derived from the incoming pulse train and which is so phased as to give the repeater maximum gain only at the center of each nominal pulse occurrence time. In completely regenerative repeaters of the type disclosed in a copending joint application of R. L. Carbrey, C. C. Cutler and C. B. H. Feldman, Serial No. 176,238, filed July 27, 1950, which issued as Patent 2,658,997, dated November 10, 1953, incoming pulses are recirculated through a loop circuit containing reshaping elements to completely reshape and accurately retime the pulses before transmitting them to the next station. In accordance with the present invention distorted pulses are only partially reshaped and retimed at each repeater. On the original premise that deep fades will not occur between adjacent repeaters, the pulses will have an opportunity to tend to become completely reshaped and retimed by passing through several successive repeaters without encountering appreciable noise or fading.

Means to change the carrier frequency at the repeaters are omitted to keep the repeaters as simple and economical as possible. If geographical conditions do not protect against overshoot, that is, if a signal emitted by one repeater may be picked up not only by the subsequent repeater but also by other down the line the route may be laid out in a zig-zag manner, the angle of deviation being primarily a function of the radiation pattern of the antenna.

The repeater cost may also be held low by utilizing pure time division for multiplexing rather than frequency division. This results in a power saving since a common output tube driven near overload may be used instead of many output tubes, that is instead of one for each channel, or instead of a common output tube operated inefficiently. Pure time division in a broad-band system means that the pulses handled will be very short if the number of channels is high. The present repeater has therefore been designed to be capable of handling extremely short pulses. For example a repeater as described in detail below is capable of handling binary pulses with a band width of over several hundred megacycles on the order of 9 millimicroseconds in length at a carrier frequency of 20,000 megacycles which permits the system to handle 2,000 channels in time division. Time division also permits flexibility in dropping channels. An important feature of the invention is that the auxiliary amplifiers required need be only narrow band devices.

In one embodiment only the main signal path requires broad-band devices.

With a repeater constructed in accordance with the present invention, it is economically feasible to space repeaters only a few miles apart; incomplete regeneration in each repeater will therefore be sufficient to maintain a high quality system. If desired, completely regenerative repeaters may be used in combination with several incompletely regenerative devices to maintain the desired quality.

These and other features and objects of the invention may be better understood from a consideration of the following detailed description when read in accordance with the attached drawings, in which:

Fig. 1 shows by a block schematic diagram an incompletely regenerative repeater embodying principles of the present invention;

Fig. 2 shows schematically a repeater of the type shown in Fig. 1;

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Fig. 3 shows illustrative expander and limiter characteristics;

Fig. 4 shows wave forms illustrative of the circuits of Figs. 1 and 2;

Fig. 5 shows by a block schematic diagram another embodiment of the invention;

Fig. 6 shows schematically a portion of the repeater shown in Fig. 5; and

Fig. 7 shows wave forms illustrative of the circuits of Figs. 5 and 6.

Referring now to Fig. 1 the signal comprising a train of microwave pulses is received by the receiving antenna 11 passed through a radio frequency filter 12 and amplified by a broad band amplifier 13. A portion of the amplifier 13 output is rectified by a crystal rectifier 14 and the rectified output is applied to an automatic gain control amplifier 15. The output of amplifier 15 acts on the amplifier 13 to hold the output of the latter constant.

Another portion of the output of amplifier 13 is applied to an expander 16 followed by a limiter 17. The expander 16 increases the amplitude of the higher level signals relative to the amplitude of the lower level signals thus tending to separate the signals from the noise and the limiter establishes a peak pulse amplitude. The output of the limiter 17 is applied to a variable gain device 18 whose gain is varied at the pulse repetition rate. There is no component of the pulse rate frequency in the envelope of the signal at the output of amplifier 13. Therefore, a control wave having a frequency equal to the pulse rate is derived by rectifying a portion of the output of amplifier 13 by a crystal rectifier 19 and by passing the rectified signal through a narrow band amplifier 20 which is tuned to the nominal pulse rate. The output of amplifier 20 is a sinusoidally varying voltage of the pulse repetition frequency.

The output of the variable gain device 18 is amplified by a broad-band amplifier 21 and the band is narrowed by a filter 22 before the signal is transmitted by the transmitting antenna 23. Putting the filter 22 ahead of amplifier 21 instead of after it may result in somewhat higher output but would permit radiation of the frequency components produced by any non-linearity in the amplifier 21.

Components to fill the blocks of Fig. 1 are shown by way of example in Fig. 2. The incoming signal from the antenna 11 is passed through the filter 12 which comprises a pair of spaced irises 26 and is then applied to the input of traveling wave amplifier 27 by the wave guide 25. Traveling wave amplifiers are described in articles in the February 1947 Proceedings of the I. R. E. entitled "Traveling wave tubes" by J. R. Pierce and L. M. Field, page 108, "Theory of beam type traveling wave tubes" by J. R. Pierce at page 111, and "The traveling wave tube as an amplifier for microwaves" by R. Kompfner at page 124. The traveling wave amplifier 27 comprises an indirectly heated cathode 29, a control grid 30, an accelerating anode 31, a helix 32 and a collector 33. The helix is biased positive with respect to the cathode by the battery 34 and the collector 33 is biased slightly less positive than the helix 32.

Output is taken from the traveling wave amplifier by wave guide 35 and applied to a wave guide hybrid junction 36. Wave guide hybrid junctions are disclosed, for example, in Patent 2,445,895 to W. A. Tyrrell, dated July 27, 1948. The *p* and *s* arms and the *a* and *b* arms of the hybrid are respectively in a conjugate relation, that is, there is no direct coupling of energy between them so that energy entering the *p* arm will divide between the *a* and *b* arms, and will not couple directly into the *s* arm. The *p* or parallel arm is so-called because energy entering the *p* arm and appearing in the *a* and *b* arms will have the same phase relation at equal distances from the junction in the *a* and *b* arms. The *s* or series arm is so-called because energy entering the *a* and *b* arms from the *s* arm will have opposite phase relations at equal dis-

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tances from the junction. No especial use is made of the conjugate properties of hybrid junction 36, rather, the hybrid junction is used merely as a convenient wave guide branching means.

Energy entering the *b* arm of hybrid junction 36 is rectified by rectifier 37 which may for example comprise a germanium crystal rectifier. A portion of the rectified output is applied to the input of the automatic gain control amplifier 15 by means of the voltage divider comprising resistors 38 and 39. The output of amplifier 15 is applied to the control grid 30 in the electron gun assembly of the traveling wave amplifier 27 in such a manner as to hold the output level of amplifier 27 constant. The output of amplifier 15 might alternatively be applied to the helix 32 of the traveling wave amplifier.

Energy entering the *a* arm of hybrid junction 36 is applied to the crystal expander 16 which is of the type disclosed in a copending application of C. C. Cutler Serial No. 118,890 filed September 30, 1949, which issued as Patent No. 2,652,541, dated September 15, 1953. The expander 16 comprises a hybrid junction similar to the hybrid junction 36 but with the *a* and *b* arms terminated in crystal rectifiers 40. The *a* and *b* arms are matched at low levels by the rectifiers 40 but as the signal level increases, the impedance of the crystal diodes changes and the *a* and *b* arms become progressively mismatched. Higher level signals will therefore be reflected into the *s* arm in increasing amounts as their amplitude increases. The *b* arm is a quarter wavelength longer than the *a* arm so that energy reflected from the *a* and *b* arms will be in phase in the *s* arm and therefore add. An illustrative crystal expander characteristic is shown by way of illustrations by curve *a* of Fig. 3. The limiter 17 is similar in structure to the expander 16. However, the rectifiers 41 which terminate the *a* and *b* arms of the limiter are matched at high levels so that the limiter has a characteristic as illustrated by curve *b* of Fig. 3. Crystal diode limiters are disclosed in a copending application of A. F. Dietrich, Serial No. 118,856, filed September 30, 1949, which issued September 15, 1953, as Patent No. 2,652,540. The over-all characteristic of the expander 16 and limiter 17 is illustrated by curve *c* of Fig. 3. It may be seen from the combined characteristic that the expander-limiter combination will discriminate in favor of the higher level signals, tending to suppress the lower levels, and will limit the higher levels to a value predetermined by the limiter. The expander and limiter therefore constitute a slicer which continually samples a given amplitude range of the incoming signal; the expander determining the lower limit of the range and the limiter the upper level. The shape of this characteristic may be adjusted by adjusting the levels at which the crystals 40 and 41 of the expander and limiter are matched to the respective wave-guide arms; this may be done, for example with the aid of a direct-current bias applied to the crystals.

The output of the limiter 17 is applied by the wave guide 42 to the variable gain device 18 which comprises a traveling wave amplifier 43 similar to amplifier 27. The sinusoidally varying voltage which controls the gain of amplifier 43 is derived as explained above from the rectified pulse train which is amplified by the narrow band pass amplifier 20. The sinusoidally varying voltage is properly phased with respect to the pulse train so that amplifier 43 will have maximum gain at the centers of the normal pulse occurrence times as will be illustrated below. The output of the variable gain device 18 is passed through amplifier 21 and a filter 22 comprising the spaced irises 44 to the transmitting antenna 23.

The variable gain device 18 may alternatively comprise a crystal diode structure such as the expander 16 or limiter 17 with the sinusoidal output voltage of amplifier 22 being applied to the crystal rectifiers as a bias. Such a device is disclosed in the aforementioned,

Carbrey-Cutler-Feldman application. The signal level at the input of amplifier 43 is low due to the loss in the expander 16 and limiter 17. Therefore, even if the variable gain device 18 is a crystal diode device it should, at this low level of operation, act as a switch and not as an expander or limiter.

It may be noted that the amplifiers other than those in the main signal path, e. g. amplifiers 15 and 20 need not be broad band devices. The repeater of Fig. 1 is therefore relatively simple, inexpensive and easy to build.

The effect of the repeater just described on an incoming signal is illustrated by the wave form shown in Fig. 4. The vertical lines 1, 2, 3 . . . 10 indicate successive pulse positions and wave form *a* is a train of binary pulses without noise. Wave form *b* illustrates what the addition of noise and/or fading may do to wave form *a*. After the signal has passed through the expander and limiter the signal will appear as curve *c*. It may be seen that the higher level signals have been increased and the lower level signals have been decreased. Although the amplitudes of the pulses have been pushed back toward their correct values some of the pulses are slightly out of time. The sinusoidal voltage which controls the variable gain device is illustrated as wave form *d* and the output of the variable gain device as wave form *e*. The tendency of the variable gain device is to relocate the pulses in their proper time positions. The output of the variable gain device, wave form *e* is of course broader band than the original signal, wave form *a*. The band, however, is narrowed by the output filter after which the signal appears as wave form *f*.

The output signal, wave form *f* of Fig. 4, is not exactly like the noiseless signal of wave form *a* but it is better than the input signal, wave form *b*, both as to pulse amplitude and pulse position. If it were recirculated through the repeater without added noise the resulting output would be still more like wave form *a*. However, the same effect may be had without recirculation if there is substantially no noise or fading between this and the next subsequent repeater. If a small amount of noise is added to wave form *f* prior to the next repeater the output of the latter will be approximately the same as wave form *f*.

An alternative embodiment of the invention is illustrated in Figs. 5 and 6. Referring now to Fig. 5 microwave pulses received by antenna 51 are amplified by broad band amplifier 52. Gain control may be applied to amplifier 52, if desired, to assure that amplifier 52 delivers pulses which have a constant average amplitude. The amplified signal is then passed through a radio frequency slicer 53 and applied to the input of a directional coupler 54. Most of the energy entering the *a* arm of directional coupler 54 will be directly coupled to the *b* arm thereof, with a smaller portion being coupled to the *d* arm; the *c* arm of the coupler is terminated in its characteristic impedance by an impedance 55.

The energy appearing in the *b* arm of the directional coupler is applied to the input of a gating tube 56 which is under the control of a sweep source 57. The sweep source 57 drives the gating tube 56 at a frequency equal to one-half the pulse repetition rate and is so phased that the gating tube will pass energy only at the center position of each pulse occurrence time. Therefore, if a pulse arrives at the input of the gating tube, a short and accurately timed pulse appears at its output. This pulse is broadened to the desired thickness by filter 58 and is amplified by amplifier 59. The amplified energy is applied to directional coupler 60 which applies most of the energy to amplifier 61 and thence to the transmitting antenna 62. It will be understood that if at a given pulse occurrence time the slicer 53 delivers no pulse to the gating tube 56 no pulse will appear at the output of the gating tube and hence no pulse will be radiated by the antenna.

To insure that the sweep source 57 is accurately synchronized with the incoming pulses, the sweep source frequency is controlled by a comparator circuit 63 which compares a sample of the signal derived from the output of the slicer 53 with a sample of the signal derived from the output of amplifier 59. These samples are derived by means of directional couplers 54 and 60 respectively. A delay line 64 is interposed between directional coupler 54 and comparator circuit 63 and has a delay equal to the delay of gating tube 56, filter 58, and amplifier 59 and associated wave guide so that the signals reach the comparator circuit 63 from the two directional couplers in synchronism. It is important to note that while large changes in the phase of the output of sweep source 57 may cause completely false signals to appear at the output of gating tube 56 small changes in the phase of the sweep source merely cause the pulses in the output of the gating tube to appear at a time slightly too early or too late.

Details of an illustrative circuit constructed in accordance with the block schematic of Fig. 5 will be explained with reference to Fig. 6. The radio frequency slicer which is not shown may be of the type disclosed in my copending application, Serial No. 225,468, filed May 10, 1951. Alternatively, it may comprise an expander-limiter combination as described above in connection with Fig. 2. In either case, it acts to pass only those signals which originated as pulses and to suppress those induced by noise. The pulses appearing at the output of the slicer 53 are applied to the directional coupler 54 which is of the type disclosed in an article entitled "Directional couplers" by W. W. Mumford appearing in the Proceedings of the I. R. E., February 1947 at pp. 160-165. The portion of the incoming signal to be applied to the comparator circuit 63 is tapped by the *d* arm of the directional coupler 54. The output pulses from amplifier 59 which appear in the *d* arm of directional coupler 60 are rectified by the crystal rectifier 65 and are used to operate what are essentially two microwave switches, controlling the signal derived from slicer 53 by means of the *d* arm of directional coupler 54 in a manner which will be explained.

The energy appearing in the *d* arm of directional coupler 54 is applied through a delay line 64 comprising a section of coaxial cable 66, cut to the proper length, to the *p* arm of a hybrid junction 67. Hybrid junction 67 divides the energy applied to its *p* arm between the two previously mentioned microwave switches which comprise hybrid junctions 68 and 69. Hybrid junctions 68 and 69 have their *a* and *b* arms terminated in crystal rectifiers 70-73 which are spaced at equal distances from their respective junctions. Rectifiers 70 and 71 ordinarily present equal radio frequency impedances to incident energy and preferably impedances which match the characteristic impedance of their respective waveguide arm as do rectifiers 72 and 73 so that there ordinarily is no signal transferred through either hybrid junction 68 or 69. However, when rectified output from crystal rectifier 65 is applied to rectifier 71 over leads 74 and 75, the impedance of rectifier 71 is made different from the impedance of rectifier 70. When these two impedances are unbalanced, the hybrid will act as a closed switch, and energy will pass from the *p* arm of hybrid junction 68 to rectifier 76, the rectified output of which produces a voltage across storage condenser 77.

Thus, a pulse applied to rectifier 65 essentially closes a connection between hybrid junction 68 and crystal rectifier 76 and allows a signal applied to hybrid junction 68 to produce an output across condenser 77. Similarly, the signal applied to rectifier 65 causes a dissimilarity in impedance between crystals 72 and 73, which terminate the *a* and *b* arms of hybrid junction 69. This effectively closes a switch between hybrid junction 69 and crystal rectifier 78 and allows signals applied to

hybrid junction 69 to produce rectified output across condenser 77.

Between hybrid junctions 68 and 69 there is interposed a delay line 79 comprising a section of coaxial conductor 80 so that the pulses from hybrid junction 67 reach hybrid junction 69 slightly out of phase with the pulses which reach hybrid junction 68. The result of this out-of-phase relationship on the rectified outputs of rectifiers 76 and 78 may be understood by reference to Fig. 7. Wave form A illustrates the pulses applied to rectifier 65 from the output of amplifier 59. When the amplitude of the signal in wave form A is maximum, the switches formed by hybrid junctions 68 and 69 are closed; when the amplitude is zero, these switches are opened. If the pulses arriving at hybrid junction 68 are exactly in phase with the opening and closing of the switch, the rectified output of rectifier 76 appearing across condenser 77 will be as illustrated by wave form B of Fig. 7, and the average voltage will be proportional to the shaded area. However, the pulses arriving at hybrid junction 69 will be delayed by an amount δt , as illustrated by wave form C, due to the delay line 79 of Fig. 6. Therefore, these latter pulses will not coincide with the closed periods of the switch 69, as shown in wave form A, and the average rectified output voltage of rectifier 78 appearing across condenser 77, which is represented by the shaded area of wave form D, will be less than the rectified output area shown by the shaded area of B. Rectifiers 76 and 78 are connected to produce opposite polarities across condenser 77. Therefore, as the phase of the pulses reaching directional coupler 54 varies with respect to the phase of the pulses reaching directional coupler 60, the voltage across condenser 77 will change in magnitude and may change in polarity because of the phenomenon illustrated by wave forms B and D of Fig. 7. As previously indicated, the phase of the pulses coming from gating tube 56 is governed by the phase of the sweep voltage produced by sweep source 57. Therefore, the voltage across condenser 77, which is a measure of the phase of the sweep voltage as compared with the phase of the pulses coming from slicer 53, may be used to control and stabilize the phase of the sweep source, i. e., to synchronize the sweep source 57 properly with the incoming pulses.

To do this, the voltage across condenser 77 is amplified by a direct-current amplifier 81 whose output is balanced to ground by resistors 82. This balanced voltage is used to control the frequency or phase of the sweep source 57 as follows. The sweep power is delivered by a pentode 83 having a cathode 84 which is grounded. The anode 85 of pentode 83 is connected to one side of a resonant output circuit comprising condenser 86 and inductance 87. Sweep output power is derived by the coil 88, which is coupled inductively to the inductance 87.

The excitation of the output tube is obtained from a coil 89 inductively coupled to inductance 87. The coil 89 is connected to two coupling coils 90 and 91 in series. Coil 90 is coupled to a resonant circuit 92 which is tuned to a frequency slightly above the desired sweep frequency while coil 91 is coupled to a resonant circuit 93 tuned to a frequency slightly below the desired sweep frequency. The tuning of resonant circuits 92 and 93 and the coupling of coils 90 and 91 to their respective resonant circuits are so adjusted that at the desired sweep frequency, the impedance looking into coil 90 from its connecting transmission line 94 is resistive and is equal to the characteristic impedance of transmission line 94. One side of resonant circuit 92 is connected to the control grid 95 of the pentode 96, the cathode 97 of which is connected to ground through resistor 98 and by-pass condenser 99. The anode 100 of pentode 96 is connected to one side of output coil 101, the other side of which is by-passed to ground by

condenser 102. The resonant circuit 93 is connected to control grid 103 of a second pentode 104 whose anode 105 is connected to the anode 100 of the first pentode 96 and whose cathode 106 is connected to cathode 97 of pentode 96.

Because of the off-tunings of the grid circuits of pentodes 96 and 104, pentode 96 is excited in a different phase from pentode 104. By changing the polarity or magnitude of the control voltage applied to resonant circuits 92 and 93 over leads 111 and 112, respectively, more current may be caused to flow through tube 96 and less through tube 104 or vice versa. Hence the components of the current supplied by the anodes 100 and 105 of the two pentodes to output coil 101 are controlled by the polarity and the magnitude of the voltage appearing across resistors 82.

The combined output of the two pentodes 96 and 104 is coupled by coil 101 into a resonant circuit 107 which is tuned to the desired sweep frequency. One side of this resonant circuit is connected to the control grid 108 of the output tube 83, the other side being connected to ground by a by-pass condenser 109 and a grid leak resistor 110.

The foregoing description shows that the phase around the feedback path from coil 89 to control grid 108 is controlled by the polarity and magnitude of the balanced output of the direct-current amplifier 81 appearing across resistors 82 and hence the frequency and phase of the voltage produced across the output coil 88 and applied to the gating tube 56 is controlled by the output of direct-current amplifier 81. If this voltage is derived from the direct-current amplifier 81 in the right phase, the control action will be such as to maintain the sweep voltage in the correct synchronization with the incoming pulses and to assure the proper operation of the overall repeater.

The gating tube comprises a traveling-wave amplifier 115 of the type described above but having a deflection coil 116 surrounding the helix 117. The output of the sweep source 57 is applied to the deflecting coil 116 by means of the leads 118 and laterally deflects the electron beam of the tube. With zero deflection, the beam is centered longitudinally in the helix and the tube will pass and amplify energy applied to its input by wave guide 119. However, a slight deflection of the beam will cause it to strike the helix and the tube will be, in effect, cut off. The sweep voltage is therefore initially phased with respect to incoming pulses to have zero deflection at the centers of each pulse position. As an alternative device, the gating tube 56 may comprise a device such as is described in my copending application Serial No. 110,851, filed August 17, 1949.

Although the invention has been described with particular reference to illustrative embodiments other modifications and embodiments will readily occur to one skilled in the art so that it should be understood that the invention is not limited to the particular embodiments herein described in detail.

What is claimed is:

1. A radio repeater for relaying radio frequency signals in the form of signal-modulated pulses which comprises means for receiving said signals, means for retransmitting said signals, and pulse regeneration means interconnecting said receiving and said retransmitting means, said pulse regeneration means comprising amplitude discriminator means for passing a fixed intermediate range of signal amplitudes and for suppressing signals having amplitudes above or below said fixed range, an amplifier, means for varying the gain of said amplifier, means for deriving from said signals a voltage which varies sinusoidally at the repetition rate of said pulses, means for applying said voltage to said gain varying means to control the gain of said amplifier, and means for connecting said amplitude discriminator means and

said amplifier in series between said receiving means and said retransmitting means.

2. A repeater for relaying and regenerating signals in the form of signal-modulated pulses comprising means for receiving said signals, amplitude discriminator means comprising means for expanding an intermediate fixed range of signal amplitudes, means for applying said received signals to said amplitude discriminator means, amplifier means, means for applying the output of said amplitude discriminator means to the input of said amplifier, means for varying the gain of said amplifier in an approximately sinusoidal manner, means for synchronizing said gain varying means with the average pulse repetition rate of said signals, and means for transmitting the output of said amplifier means.

3. The combination in accordance with claim 2 wherein said synchronizing means comprise means to compare the incoming pulse occurrence times with the outgoing pulse occurrence times, means to derive from said comparison a voltage which varies as the relative pulse occurrence times vary, and means to apply said voltage to said amplifier to vary its gain.

4. The combination of means for relaying microwave pulses which comprises means to receive said pulses, an expander, a limiter, a variable gain amplifier, and means to retransmit said pulses all connected in circuit, rectifying means, means to apply said pulses to said rectifying means, a narrow band filter tuned to the nominal pulse rate, means to apply the rectified pulses to said filter, and means to apply the output of said filter to said variable gain amplifier to vary its gain.

5. Means for relaying radio frequency pulses which comprise means to receive said pulses, means to retransmit said pulses, a circuit interconnecting said receiving means and said retransmitting means which includes amplitude discriminator means the input-output characteristic of which includes an intermediate region of expansion, an amplifier, and a shaping filter, means comprising a rectifier and a narrow band filter tuned to the nominal pulse rate to derive from the received pulses a voltage varying at a frequency approximately equal to an integral multiple of one-half of the repetition rate of said pulses and means to apply said voltage to said amplifier to vary the gain thereof in a sinusoidal manner.

6. Means for relaying radio signals in the form of signal-modulated pulses which comprise means to receive said signals, amplitude discriminator means to pass signals lying within a predetermined amplitude range in preference to all others, a variable gain amplifier employing an electron beam, the gain of said amplifier being a function of the trajectory of said electron beam, means to pass said received signals through said amplitude discriminator means and said amplifier, means to derive from said received signals a voltage which varies in an approximately sinusoidal manner at a frequency substantially equal to an integral multiple of one-half of the incoming pulse repetition rate, means to apply said voltage to said amplifier to deflect said electron beam, output means including a shaping filter and means to apply said signals to said output means after passing them through said amplitude discriminator means and said amplifier.

7. Radio relay means for relaying microwave radio signals in the form of signal-modulated pulses which comprise means to receive said signals, amplitude discriminator means to pass the signals lying within a predetermined amplitude range in preference to all other, a variable gain amplifier employing an electron beam, the gain of said amplifier being a function of the trajectory of said beam, means to laterally deflect said electron beam in a recurrent manner at a rate approximately equal to an integral multiple of one-half of the normal incoming pulse repetition rate, means to synchronize

said last-named means with the incoming pulses which comprises means to compare a sample of the incoming pulses with a sample of the pulses delivered by said amplifier, means to derive a voltage which varies in accordance with said comparison, and means to apply said voltage to said deflection means as a control therefor, output means including a filter and means connecting said amplitude discriminator means and said variable gain amplifier in circuit between said receiving means and said output means.

8. The combination in accordance with claim 7 wherein said amplifier comprises a traveling wave amplifier.

9. Apparatus for regenerating radio signals in the form of signal-modulated pulses which comprises an input circuit, means to apply said signal waves to said input circuit, an output circuit, amplitude discriminator means including an expander and a limiter and variable impedance means connected in circuit between said input and output circuit, means to vary said impedance which comprise a rectifier and a narrow band amplifier tuned to a frequency approximately equal to the normal incoming pulse repetition rate connected in circuit, means to impress a portion of the input signals on said last-named circuit, and means to impress the output of said amplifier on said variable impedance with the proper phase to cause said impedance to be a minimum during the normal pulse occurrence times.

10. The combination in accordance with claim 9 wherein said variable impedance means comprises an amplifier.

11. A microwave repeater for signals in the form of signal-modulated pulses, said repeater having a main signal path including means to receive incoming signals, means to amplify said signals, means to selectively pass the signals lying within a predetermined amplitude range comprising an expander and a limiter, a variable impedance means, an output filter, and means to retransmit said signals, and an auxiliary circuit to insure proper timing of said pulses which comprises means to derive from said incoming signals a substantially sinusoidal voltage having a frequency approximately equal to the normal pulse rate, and means to apply said voltage to said variable impedance means to vary said impedance.

12. A radio repeater for relaying and regenerating signals in the form of signal-modulated pulses comprising means for receiving said signals, amplitude discriminator means having a transmission characteristic including a range of expansion for higher amplitude input signals and ranges of suppression for signals above and below said higher amplitude signals, means for applying said received signals to the input of said amplitude discriminator means, a traveling-wave amplifier having an input, an output, means providing a wave interaction path intermediate said input and output, and means for forming an electron beam which flows along said path, means for applying the output of said amplitude discriminator means to the input of said amplifier, means for modulating said electron stream, means for deriving from said signal modulated pulses a modulating voltage which has a frequency substantially equal to the average repetition rate of said pulses, means for applying said modulating voltage to said modulating means, and means for transmitting the output of said traveling-wave amplifier.

13. The combination in accordance with claim 12 wherein said modulating means comprises means for varying the density of said electron beam.

14. The combination in accordance with claim 12 wherein said modulating means comprises means for laterally deflecting said electron beam.

15. A radio repeater for relaying radio frequency signals in the form of signal-modulated pulses which comprises means for receiving said signals, a slicer comprising amplitude discriminator means for passing signals within an intermediate amplitude range and for suppressing signals above or below said range, means for applying

ing said received signals to said slicer, an amplifier having an input and an output, means for applying the output of said slicer to the input of said amplifier, and means for varying the gain of said amplifier in an approximately sinusoidal manner in synchronism with the average repetition rate of said signal-modulated pulses.

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