

Feb. 17, 1942.

M. G. CROSBY

2,273,090

SUPERREGENERATIVE LIMITER

Filed Feb. 3, 1940

6 Sheets-Sheet 1



INVENTOR
MURRAY G. CROSBY
BY *H.S. Grover*
ATTORNEY

Feb. 17, 1942.

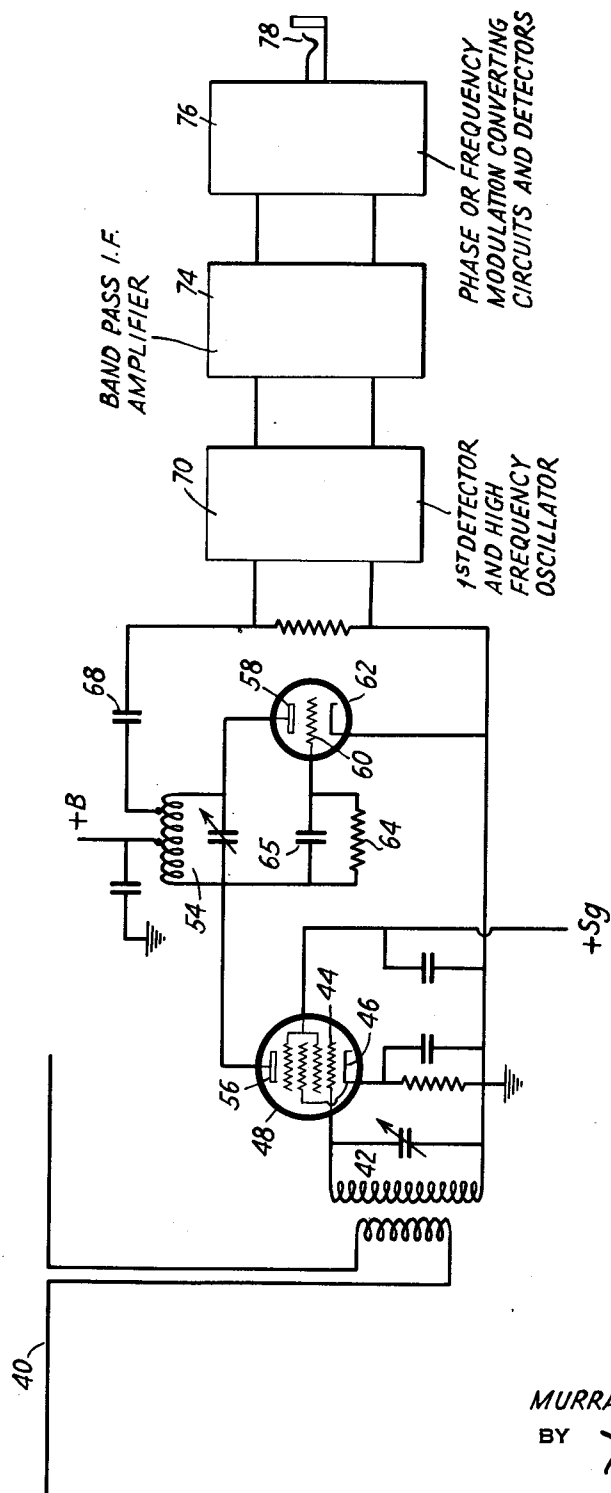
M. G. CROSBY

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SUPERREGENERATIVE LIMITER

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6 Sheets-Sheet 2



INVENTOR
MURRAY G. CROSBY
BY *H.S. Snover*
ATTORNEY

Feb. 17, 1942.

M. G. CROSBY

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6 Sheets-Sheet 3

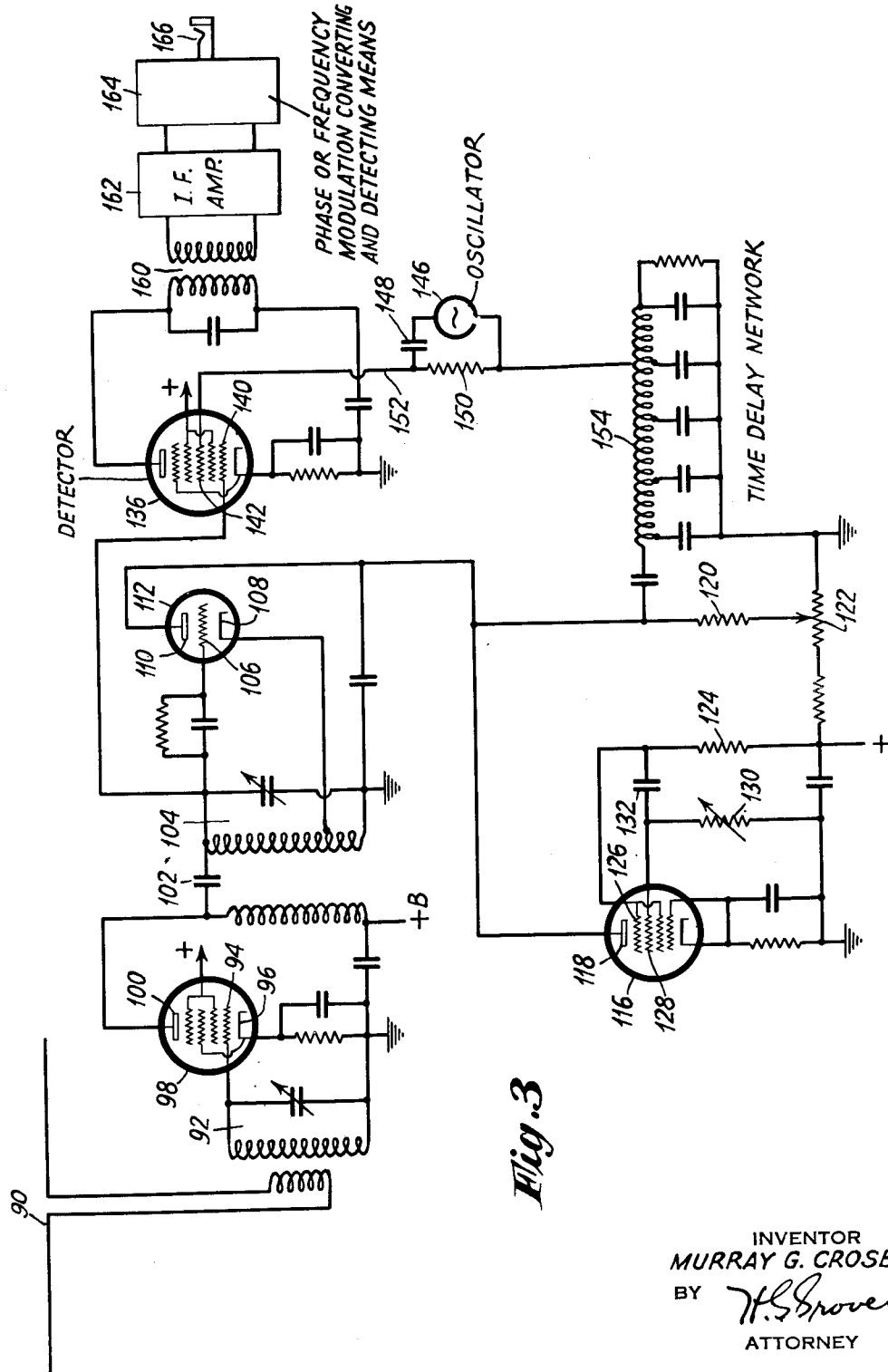


Fig. 3

INVENTOR
MURRAY G. CROSBY
BY *H. S. Grover*
ATTORNEY

Feb. 17, 1942.

M. G. CROSBY

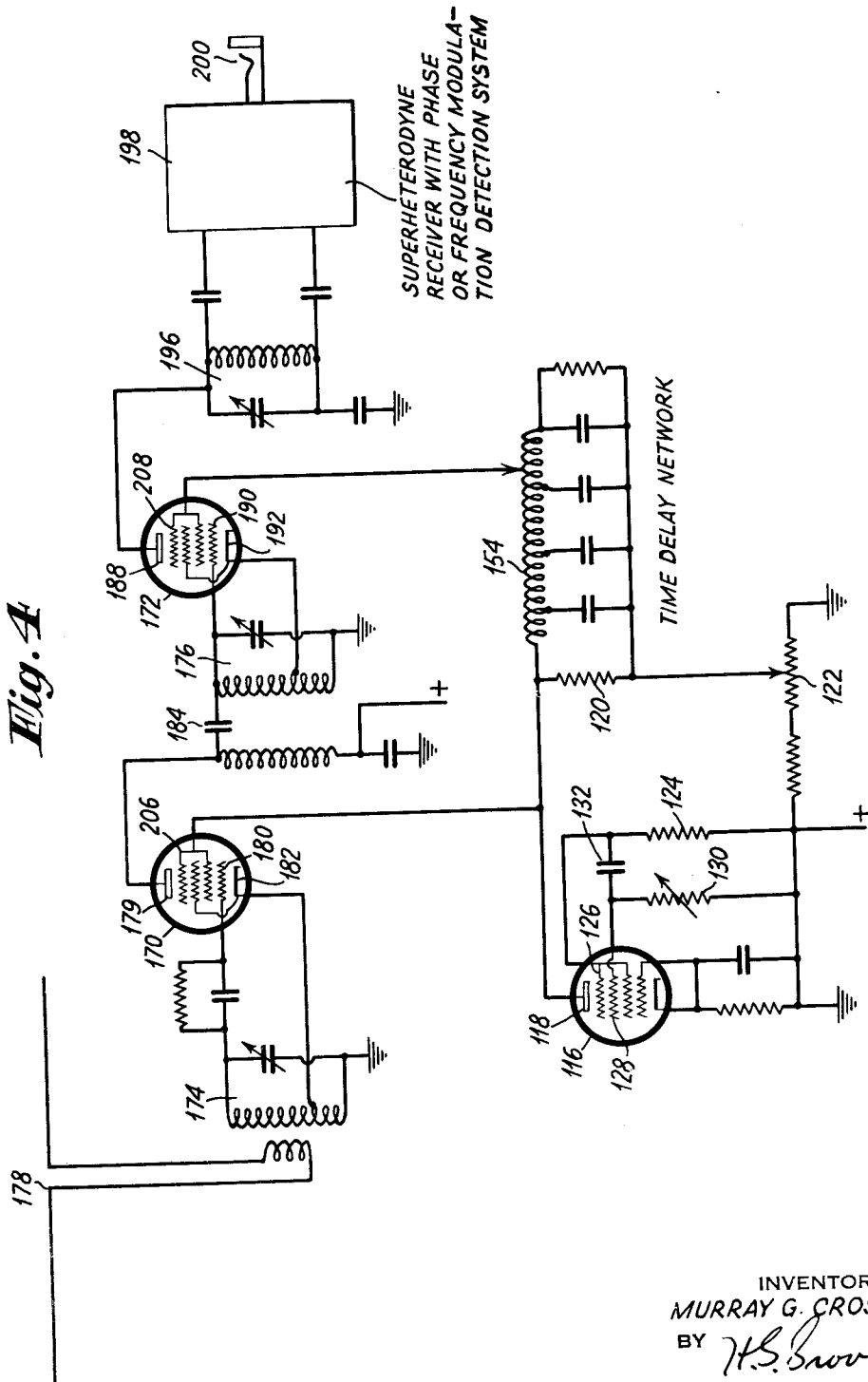
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Fig. 4



INVENTOR
MURRAY G. CROSBY
BY *H.S. Snover*
ATTORNEY

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SUPERREGENERATIVE LIMITER

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Fig. 5a

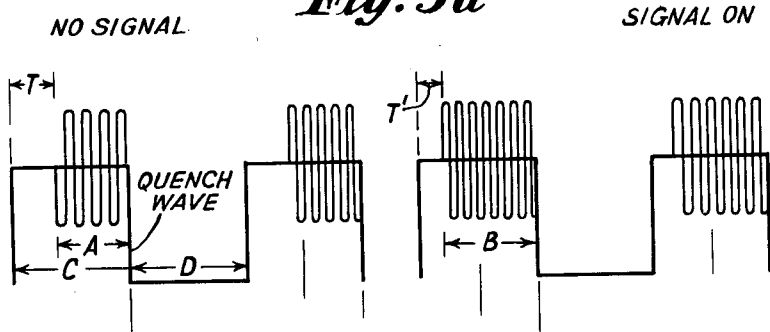


Fig. 5b

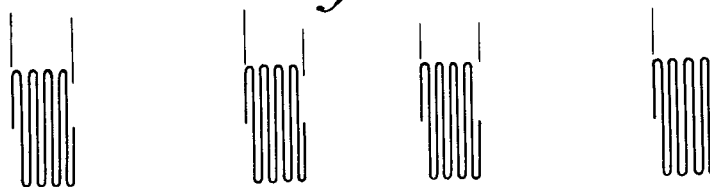
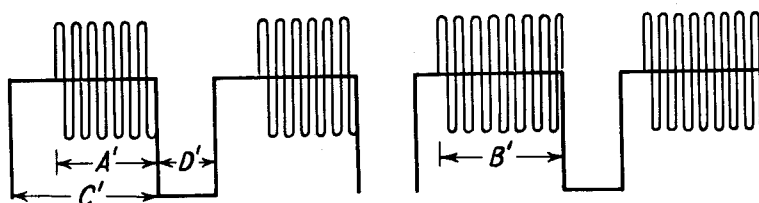


Fig. 5c



Fig. 5d



INVENTOR
MURRAY G. CROSBY
BY *H. S. Swales*
ATTORNEY

Feb. 17, 1942.

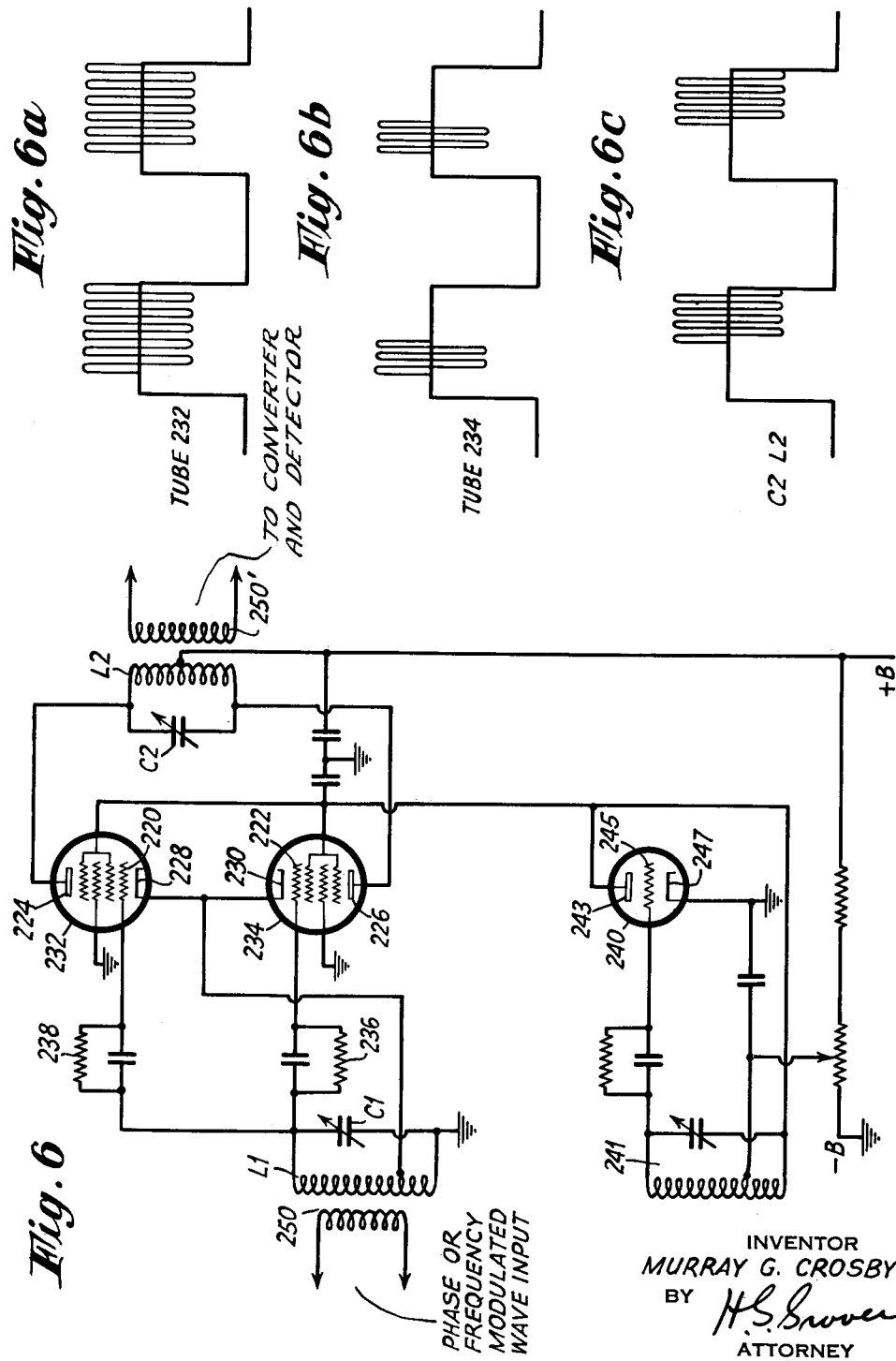
M. G. CROSBY

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SUPERREGENERATIVE LIMITER

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UNITED STATES PATENT OFFICE

2,273,090

SUPERREGENERATIVE LIMITER

Murray G. Crosby, Riverhead, N. Y., assignor to
Radio Corporation of America, a corporation of
Delaware

Application February 3, 1940, Serial No. 317,041

17 Claims. (Cl. 250—20)

This application concerns use of the principle of super-regeneration to provide a limiting effect for removing amplitude variations from signals such as frequency and phase modulated signals or keyed signals. Several different arrangements of super-regenerative amplifiers are disclosed which use either the conventional super-regenerative circuits or circuits with improvements to make them especially adapted to the function of limiting.

In describing my invention, reference will be made to the attached drawings wherein Figures 1, 2, 3, 4, and 6 each show different modifications of my improved frequency modulated wave amplitude limiting means, including super-regenerative oscillators, with means for applying frequency modulated waves thereto, quenching means and means for deriving limited frequency modulated waves therefrom and utilizing the same. Figures 5a, 5b, and 5c are graphs used to illustrate the limiting action of the oscillator, while Figures 6a, 6b, and 6c are used to illustrate the operation of the modification illustrated in Figure 6.

In the prior art of limiting circuits, the practice has been to use an amplifier which was fed by a signal strong enough to load it to saturation so that a constant output is obtained regardless of the input amplitude variations. In the usual case, however, this type of limiter has the characteristic that when the input is increased beyond saturation to an appreciable degree, the output of the amplifier decreases. This decrease in output is just as undesirable as an increase in output for most limiter uses. Consequently, the expedient that is resorted to is to cascade alternate stages of amplification and limiting.

The cascade arrangement involves a large number of tubes with their associated coupling networks so that an effective limiter of this type involves considerable equipment. It is the purpose of this application to disclose an improved limiter based on the principle of super-regeneration which not only involves less equipment, but can be made more effective than limiters known heretofore.

The theory of super-regenerative reception has been described by Hikosaburo Ataka in an article entitled: "On super-regeneration of an ultra-short wave receiver," published in the August 1935 issue of the Proceedings of the I. R. E. Further theory is described by Frederick W. Frink in an article entitled: "The basic principles of super-regenerative reception," published in the January 1938 issue of the Proceedings of

the I. R. E. Briefly, the theory of super-regeneration is that the quench frequency stops the oscillating detector from oscillating during one half cycle of the quench frequency and allows it to build up a sustained oscillation during the other half cycle. This is shown in Fig. 5a in which a square wave form quench frequency is used. With no signal applied to the circuit, the oscillations start after a time T has elapsed and continue for the time A. During the part of the quench cycle marked D the oscillations are quenched or stopped. With signal present, the oscillations start after the time T' has elapsed and continue for the time B which is longer than the time A. In reality, this time T' is shorter than the time T by virtue of the fact that the presence of the signal increases the rate of build-up of the oscillations; however, the resultant effect upon the energy contained in the radio-frequency oscillation is the same as though the signal merely started the oscillations at an earlier time.

From a comparison of the "No signal" and "Signal on" diagrams of Fig. 5a, it can be seen that the difference between the radio-frequency energy present with no signal and that present with signal is rather small in percentage. That is, the distance A is different from the distance B by a small percentage of either distance. Consequently, when an amplitude modulated signal is applied to this circuit, the percentage of amplitude modulation appearing in the super-regenerated radio-frequency energy will be smaller than that existing on the applied modulated wave. This phenomena is relied upon to produce the limiting action in the invention of this application. The modulated signal which it is desired to limit is applied to a super-regenerative amplifier and the radio-frequency energy built up by the super-regenerative effect is utilized as the limited signal. The ordinary super-regenerative oscillator, used as a regenerative amplifier instead of in the conventional manner as a detector, produces considerable limiting action, but the improved arrangements described herein are capable of practically complete limiting. By the generic expression "angular velocity-modulated carrier waves" used in the claims is meant frequency, or phase, modulated carrier waves, as distinguished from amplitude modulated carrier waves.

The circuit of Fig. 1 shows how the ordinary separately-quenched super-regenerative amplifier may be used as a limiter in a frequency modulated wave receiver, such as a frequency or

phase modulation receiver. In this circuit the signal is received on antenna 1 and converted to intermediate frequency by radio-frequency amplifying, heterodyning and demodulating means in unit 2 and intermediate-frequency amplifiers and band-pass filters in unit 3 which contain the necessary elements of a superheterodyne receiver. Tuned circuit 4, which is coupled to the output of the apparatus in unit 3, is the super-regenerative oscillating circuit which oscillates by virtue of its connection in the negative transconductance circuit consisting of the screen grid 6, coupling condenser C, suppressor grid 8 of tube 10. The tube 10 is operated with its plate 12 at a voltage lower than the voltage applied to the screen grid 6 so that the well-known negative resistance characteristic is obtained between the suppressor grid and the screen grid. The quench oscillator 16 is coupled by transformer 18 to the control grid 20 so that on the positive half cycles of the quench oscillations, the negative resistance is present to allow oscillations to build up in tuned circuit 4, and on the negative half cycles the control grid is biased negative so that the negative resistance is absent. This quench oscillator may be either of square wave form or of sinusoidal wave form.

The radio-frequency portion of the oscillations built up in circuit 4 are electron-coupled to the plate 12 of tube 10 and appear in the tuned primary 24 of transformer 26 to be passed by the tuned secondary 28 thereof to unit 30 which contains the means for converting the frequency or phase modulation into amplitude modulation and detecting the same. If desired, the degree of wave length deviation may be increased by tuning the circuits 24 and 28 of transformer 26 to a harmonic of the oscillations produced in circuit 4 which are of the same frequency as the incoming signal. This is because, as disclosed more in detail in my United States Patent #2,081,577, dated May 25, 1937, and in my United States Patent #2,112,881, dated April 5, 1938, multiplication of the frequency of the wave correspondingly multiplies the modulation deviation thereof.

In the conventional use of the super-regenerative circuit, detection is accomplished and it is the detected or audio-frequency potentials that are utilized in the output. In the use shown here, it will be noted that the radio-frequency oscillations that are built up are not detected within the tube, but are passed on as radio-frequency energy. This energy consists of pulses of oscillations which appear once per cycle of the quench frequency. When the pulses are passed through a selective circuit such as a tuned circuit or a tuned transformer, the pulsations are smoothed out so that the quench frequency does not appear in the output which is fed to the frequency or phase modulation converting circuits. In the circuit of Fig. 1, the tuned primary 24 and tuned secondary 28 of transformer 26 performs this function which amounts to the removal of the side frequencies produced by the quench frequency.

The arrangement of Fig. 2 differs from that of Fig. 1 in that the limiter is placed in the radio-frequency circuit of the receiver instead of the intermediate-frequency circuit. The arrangement of Fig. 2 also utilizes the self-quenching instead of the separately-quenched super-regenerative circuit. Placing the limiter in the radio-frequency portion of the receiver has the advantage that the super-regenerative action

builds up the signal to a high level early in the receiver so that less amplification is required in the receiver. The use of a self-quenching super-regenerative circuit eliminates the necessity of the separate quench oscillator tube. In this circuit, the signal is received on antenna 40, induced in tuned circuit 42, the latter being coupled with the grid 44 and cathode 46 of amplifier tube 48. The amplified wave appears in the tuned circuit 54 coupled with the anode 56 of tube 48. Tuned circuit 54 is the super-regenerative oscillating circuit coupled between the anode 56 and grid 60 of the super-regenerative oscillator tube 62. As is conventional with a self-quench oscillator, a high value of grid leak 64 is used and positive voltage is fed from the plate supply through the grid leak 64 to the control grid 60 of oscillator tube 62. The grid leak is shunted by condenser 65. Part of the radio-frequency energy from the oscillating circuit 54 is fed through coupling and blocking condenser 68 to the detector and beating oscillator included in unit 70 where it is heterodyned to intermediate frequency and passed through the band-pass intermediate-frequency amplifier 74 to the frequency or phase modulation detecting system 76.

In the circuit of Fig. 3 a novel means is utilized to remove the variable part of the built-up oscillations so that the degree of limiting is made practically complete. By a study of Fig. 5a, it can be seen that if the first part of the operational part of the quench cycle were removed, the radio-frequency energy would have the characteristic as shown in Fig. 5b and would have the same average value whether signal was present or not. The circuit of Fig. 3 shows a means for quenching off the first part of the built-up oscillations so that this high degree of limiting is obtained. Signal is received on antenna 90 and fed through radio-frequency circuit 92 to the grid 94 and cathode 96 of amplifier 98 which has its anode 100 coupled through condenser 102 to the super-regenerative oscillating circuit 104 connected with the grid 106, cathode 108 and anode 110 of the oscillator tube 112. The oscillator tube 112 is modulated by the quench voltage from tube 116. Tube 116 is connected as a negative transconductance tube with its plate voltage lower than its screen voltage. The anode 118 of tube 116 is supplied by resistance 120 with a direct-current potential from resistance 122 lower than the direct-current potential supplied by resistance 124 to screen grid 126. This produces a negative resistance between the suppressor grid 128 and screen grid 126 so that resistors 130 and 124 in conjunction with condenser 132 will form a multivibrator circuit. The output of a multivibrator circuit is not exactly square wave form, but I have found that with this circuit there is a limiting effect produced by taking the output from the plate circuit which squares off the wave form. This square wave form voltage appearing at the plate of tube 116 is used as the plate voltage for tube 112 so that tube 112 may oscillate on the positive halves of the cycle.

Tube 136 is the heterodyne detector which has fed energy to its signal grid 140 from the super-regenerative amplifier 112, and a combination of quench voltages and beating oscillator voltage is supplied to the injector grid 142. The beating oscillator voltage is fed from source of oscillations 146 through condenser and resistance coupling 148 and 150 to the injector grid lead 152. The square wave form quench voltage is fed from resistor 120 through variable time delay

network 154 to the injector grid lead 152. This quench voltage is time delayed just enough to make detector 136 inoperative during the first part of the operational half of the quench voltage upon which the super-regenerative amplifier operates. That is, the quench voltage is fed to the detector 136 so as to allow it to operate only after the time T has elapsed on the half wave of the super-regenerative oscillator quench voltage. This rejects the portion of the radio-frequency oscillations which are dependent upon the signal amplitude so that the radio-frequency pulses which operate the detector have the form shown in Fig. 5b. It has been shown in the above mentioned articles on the theory of super-regeneration that the built-up oscillations have the same frequency as the incoming signal and will follow frequency or phase variations. Consequently, this limiter will convey the frequency or phase modulations on the wave, but will remove the amplitude variations. Intermediate frequency energy is available at transformer 160 for subsequent selection in intermediate frequency amplifier 162 and conversion to amplitude modulation for detection in unit 164 for utilization at 166.

In the circuit of Fig. 4, the same principle is used as in the circuit of Fig. 3, but instead of quenching the subsequent heterodyne detector or an amplifier at the proper time, a second super-regenerative amplifier is arranged to amplify the output of the first and their quench voltages are relatively time delayed so that the second does not start operating until the first has operated long enough for the variable part of the oscillation to transpire. Thus, the oscillator operates with a quench and radio-frequency wave as shown by Fig. 5a and the second oscillator has them also, but they are time displaced as shown in Fig. 5c. This makes the second oscillator receive its exciting voltage from the first oscillator at a time after the first oscillator has been built up to full amplitude. Since this full amplitude is constant, the signal which excites the second super-regenerative amplifier is constant so that its output is constant.

The two super-regenerative amplifiers in Fig. 4 consist of tubes 170 and 172 with their respective oscillating circuits 174 and 176. The tuned circuit 174 is coupled to antenna 178 and regeneratively connected to the anode 179, grid 180 and cathode 182 of tube 170. The anode 179 of tube 170 is coupled by condenser 184 to circuit 176. Tuned circuit 176 is regeneratively connected to the anode 188, grid 190, and cathode 192 of tube 172. A tuned circuit 196, connected with the anode 188, supplies output to unit 198. The unit 198 includes an oscillator first detector, intermediate-frequency amplifier, phase or frequency modulated wave converter and detector system.

Quench voltage is fed directly from the plate 118 of square wave form generator tube 116 to the screen grid 206 of the first amplifier tube 170 and through a time delay network 154 to the screen grid 208 of tube 172.

The oscillator 116 and its circuits including the time delay network 154 in Figures 3 and 4 are substantially similar and since it has been described in detail in connection with Figure 3, it will not be described in detail again in connection with Figure 4.

The radio-frequency output appears in tuned circuit 196 which is in the plate circuit of the second super-regenerative amplifier 172. If de-

sired, tuned circuit 176 may be tuned to a harmonic of the frequency to which circuit 174 is tuned so that a frequency multiplication takes place to multiply phase or frequency deviations. Likewise, and for the same purpose, circuit 196 may be tuned to a harmonic of the frequency to which circuit 176 is tuned.

In the circuit of Figure 6, I show another novel means for removing the variable portion of the built-up oscillations. A resonant circuit comprising L1, C1 is regeneratively connected to the grids 220 and 222, anodes 224 and 226 and cathodes 228 and 230 of tubes 232 and 234, respectively, so that they both oscillate at the same frequency if they are adjusted the same. However, one of the tubes, say 234, is made partially self-quenching as shown in the diagram of Figure 6b. The other tube 232 is merely quenched by the quenching oscillator 240 which may be either of square or sinusoidal wave form. This partial self-quenching is produced by the use of a high resistance grid leak 236. Thus, in Fig. 6, tube 232 has a relatively low resistance grid leak 238 so that self-quenching is absent and tube 234 has a high resistance grid leak 236 so that as soon as the oscillations build up they are quenched by the bias provided by the grid leak 236. The phase or frequency modulated waves are supplied at 250 to control the operation as described hereinbefore and the limited phase or frequency modulated waves are supplied from output inductance 250' to converting and detecting means. This means may comprise apparatus as included in unit 30 of Figure 1 where the input to 250 is taken from a heterodyne receiver or may comprise the apparatus included in units 70, 74 and 76 of Figure 2 when the input at 250 is at radio frequency.

When the waves of Figs. 6a and 6b are combined in push-pull in the circuit C2, L2 connected to the anodes 224 and 226, the wave of Fig. 6b bucks that of 6a so that the resultant is as shown in Fig. 6c. Thus, the initial or variable part of the oscillations is cancelled and only the non-varying portion remains. Since this latter portion of the oscillations is independent of the signal amplitude, a constant output is obtained which will be completely limited.

The oscillator including tube 240 may be of conventional form and include a tuned circuit 241 regeneratively connected with the anode 243, grid 245, and cathode 247 of tube 240.

The waves as graphically represented in Fig. 5d show how the ordinary super-regenerative amplifier may be adjusted to produce a higher degree of limiting by using a specially shaped quench wave form. By making the marking portion of the quenching wave, C', longer than the space portion, D', the built-up oscillations persist for a longer time. This makes the variable portion, which varies in accordance with signal amplitude, small compared to the total duration of the oscillations in the operational half of the quench cycle. Consequently, the percentage of amplitude modulation appearing on the radio-frequency output of the super-regenerative amplifier is less than it would have been with a quench wave such as shown in Fig. 5a. In other words, (C'-A') is smaller compared to C' than (C-A) is compared to C. Hence, a higher degree of limiting will be obtained.

Many means may be used to provide the quenching frequency alterations of unequal time duration. For example, I may use a pair of triode systems 300 connected between the second-

ary winding of transformer 18 and the electrode 20, as shown in Fig. 1, to supply the said quench frequency instead of supplying the same directly from the source 18. To do so, the switch 302 is moved from contact 304 to contact 306 and the limiter comprising the two triode systems in a single envelope 300 (separate tubes may be used) are operated as described in detail in my United States application #275,151, filed May 23, 1939.

With this circuit in order to obtain a wave form such as shown in Figure 5d, the variable arm of potentiometer 308 is adjusted to the ground or low potential end of the potentiometer so that no bias voltage is applied to grid 310 of tube 300. The arm of potentiometer 312 is adjusted to provide a finite positive bias voltage to grid 314 of tube 300. This positive voltage on grid 314 causes the current through cathode 316 to increase. The increase of current through resistance 318, thereby makes the voltage of both cathodes more positive. The resultant effect is to make the grid 310 more negative so that it is closer to its cut-off voltages. Similarly, by reversing the relative positions of the arms of potentiometers 308 and 312 so that a positive voltage is applied to grid 310, the grid 314 of tube 300 will become more negative and a wave form which is the mirror image of that previously obtained will appear in the output. The wave fed in accordingly is altered in form in that the alterations thereof are made of unequal length. The amplitude is limited because a positive change on the grid 314 of tube 300 effects a resultant negative change on the grid 310. This phase reversal causes the electron system, comprising grid 310 and cathode 328, to cause negative grid limiting for the positive half cycles of the input wave. When grid 314 is swung negative, negative grid cut-off limits the change in cathode current caused by the input wave. When the grid 314 is swung positive, grid 310 is effectively swung negative until negative cut-off is reached.

What is claimed is:

1. Means for frequency multiplying frequency modulated carrier wave energy comprising in combination, a super-regenerative amplifier constructed to provide oscillations of substantially constant amplitude, means for impressing said wave energy to be multiplied on said amplifier, and means for deriving frequency multiplied wave energy from said amplifier.
2. Means for frequency multiplying frequency modulated carrier wave energy comprising in combination, a super-regenerative amplifier tube having electrodes connected in an oscillatory circuit to produce oscillations of substantially constant amplitude, means for impressing said wave energy to be multiplied on said amplifier, and means for deriving frequency multiplied wave energy from said amplifier.
3. Means for frequency multiplying and simultaneously limiting the amplitude of angular velocity-modulated wave energy comprising in combination, a super-regenerative amplifier constructed to produce oscillations of constant amplitude, means for impressing said wave energy on said amplifier, and means for deriving wave energy of increased frequency limited as to amplitude from said amplifier.
4. Means for frequency multiplying and simultaneously limiting the amplitude of frequency modulated wave energy comprising in combination, a super-regenerative amplifier tube constructed and arranged to provide oscillations of constant amplitude, means for impressing said

modulated wave energy on said amplifier, and means for deriving frequency modulated wave energy of multiplied frequency limited as to amplitude from said amplifier.

5. A wave limiter comprising in combination, a plurality of super-regenerative amplifiers connected in cascade, each amplifier being constructed to produce oscillations of substantially constant amplitude, means for impressing angular velocity-modulated carrier energy to be limited thereon, and means for deriving limited wave energy therefrom.

6. A wave energy amplitude limiter comprising in combination, a super-regenerative amplifier constructed to provide oscillations of constant amplitude, means for impressing angular velocity-modulated wave energy to be limited thereon, a second super-regenerative amplifier, means for impressing wave energy from said first amplifier on said second amplifier, and means for interrupting the operation of said second super-regenerative amplifier during the variable part of the oscillatory period of the first super-regenerative amplifier.

7. A wave energy amplitude limiter comprising a first super-regenerative amplifier constructed to provide oscillations of substantially constant amplitude, means for impressing angular velocity-modulated wave energy to be limited thereon, a second super-regenerative amplifier, means for impressing wave energy from said first amplifier on said second amplifier, and means for relatively adjusting the quenching frequency of said amplifiers so that said second regenerative amplifier is inoperative during the variable part of said first super-regenerative oscillations.

8. A modulated wave limiter comprising in combination, a pair of super-regenerative amplifiers connected in cascade, each of said amplifiers being constructed and arranged to provide substantially constant amplitude oscillations means for impressing angular velocity-modulated waves on the first of said cascaded super-regenerative amplifiers, means for quenching the oscillations of said amplifiers by quenching oscillations displaced in time so that the second amplifier is excited only by the constant part of the oscillations of the first amplifier, and means for deriving modulated waves from the last of said super-regenerative amplifiers.

9. A wave energy amplitude limiter comprising a first super-regenerative amplifier constructed to provide oscillations of substantially constant amplitude, a separate source of quenching oscillations therefor, a second super-regenerative amplifier constructed to provide oscillations of substantially constant amplitude including means for quenching the operation thereof, separate means for quenching the operation of said first super-regenerative amplifier, means for impressing wave energy to be amplitude limited on the both of said amplifiers, and means for combining the outputs of said amplifiers in opposition, to cancel and remove the variable part of the oscillations.

10. A wave amplitude limiter comprising in combination, a first super-regenerative amplifier constructed to provide substantially constant amplitude oscillations, a separate source of quenching oscillations therefor, a second super-regenerative amplifier constructed to provide substantially constant amplitude oscillations including means for quenching the operation thereof, separate means for quenching the operation of said first regenerative amplifier in synchronism

with the quenching of said first amplifier, means for impressing modulated wave energy to be limited on the first of said amplifiers, and means for combining the outputs of said amplifiers in opposition, to cancel and remove the variable part of the oscillations.

11. A wave energy amplitude limiter comprising in combination, a super-regenerative amplifier constructed and arranged to produce oscillations of substantially constant amplitude, a source of alternating current the alternations of which are separated by unequal time duration coupled with said amplifier for quenching the operation thereof, means for impressing angular velocity-modulated wave energy to be limited on said amplifier, and means for deriving limited wave energy from said amplifier.

12. In a system for limiting the amplitude of wave length modulated wave energy and simultaneously frequency multiplying the frequency of the wave length modulated wave energy to thereby increase the degree of modulation and demodulating the same, an electron discharge device having a plurality of electrodes, an input circuit connected between a pair of said electrodes, an output circuit connected between another pair of said electrodes, means for coupling said electrodes and energizing the same by direct-current potentials whereby said tube and circuits operate as a super-regenerative oscillator, means for impressing wave length modulated wave energy on said input circuit, means for deriving limited wave length modulated wave energy from said output circuit, and means for tuning said output circuit to a harmonic of the frequency to which said input circuit is tuned.

13. In a wave length modulated wave limiting system, a plurality of coupled cascade super-regenerative amplifiers including a source of quenching oscillations, means for impressing wave length modulated wave energy on the first of said amplifiers, means for deriving wave length modulated wave energy from the last of said amplifiers, means for applying oscillations to said amplifiers for quenching the operation of the

same, and means for causing a delay in the application of the quenching oscillations to certain of said amplifiers.

14. In means for limiting amplitude variations on frequency modulated carrier wave energy, an oscillation generator of the super-regenerative type comprising an oscillation generator tube having electrodes coupled in an oscillatory circuit, means for energizing the electrodes of said tube to produce therein oscillations of constant amplitude, means for interrupting said oscillations periodically, means for entraining said oscillator with said modulated carrier wave energy.

15. In a frequency modulated carrier wave receiver, a super-regenerative circuit comprising an oscillator generator tube having electrodes connected in an oscillatory circuit to produce oscillations of constant amplitude, means for quenching the oscillations of said generator periodically, means for impressing frequency modulated carrier wave energy of variable amplitude on said generator to entrain the generator oscillations.

16. In a limiter network for signals of variable frequency, an oscillation generator tube having electrodes coupled in an oscillatory circuit, means for energizing the electrodes of said tube to produce therein oscillations of substantially constant amplitude, means for interrupting said oscillations periodically, and means for entraining said oscillator with variable frequency signals having amplitude variations to be eliminated.

17. An amplitude limiter network, for angular velocity-modulated carrier waves, comprising a super-regenerative amplifier constructed to provide oscillations of substantially constant amplitude, means for applying said waves to said amplifier, a modulated wave transmission circuit following said amplifier, means for supplying modulated wave energy from the said amplifier to said transmission circuit, and means for preventing transmission through said transmission circuit during the variable part of the oscillatory period of said super-regenerative amplifier.

MURRAY G. CROSBY.