G_4 and the space charge of the virtual cathode formed in front of this grid. Inasmuch as the space charge pulsates at the oscillator frequency, the effect of this capacity coupling to the space charge is to cause oscillator-frequency currents to flow from grid G_4 through the tuned input circuit to ground. Trouble from this cause becomes more pronounced at high frequencies and as the percentage difference between local oscillator and signal frequencies is reduced.[1] The result is that the pentagrid converter, while entirely satisfactory for use with signals of broadcast and lower frequencies, becomes increasingly unsatisfactory with signals of higher frequency.

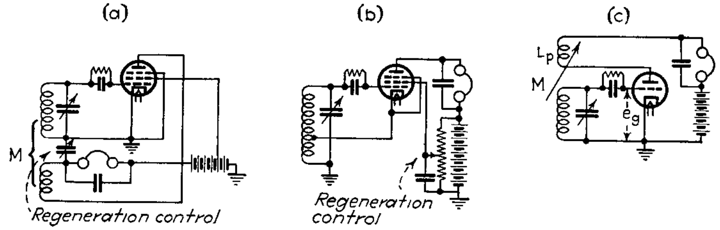

FIG. 253.—Typical circuits for regenerative and oscillating detectors. The telephone receivers indicated in the figure can be replaced by an amplifier when further amplification is desired.

89. Regenerative and Oscillating Detectors.—In examining the action taking place in detectors employing either grid or plate rectification it will be noted that there are signal currents flowing in the plate circuit of the detector, in addition to the products of rectification, as is clearly shown in Figs. 240 and 244. It is possible to obtain regeneration by feeding back a portion of this signal energy to the circuits associated with the detector input by means such as illustrated in Fig. 253. Regeneration produced in this way by utilizing the radio-frequency energy in the detector plate circuit can be more readily controlled than regeneration in amplifiers, and is occasionally used to increase the amplification and selectivity of radio receivers.

Regeneration in detectors produces exactly the same action as regeneration in radio-frequency amplifiers, since the regenerative detector is essentially a radio-frequency amplifier as far as the feedback is concerned. The effect of regeneration, no matter how produced, is equivalent to altering the effective resistance and effective reactance of the input circuit. The change of reactance caused by regeneration alters the resonant frequency slightly, making the resonance point somewhat dependent upon the adjustment of the regenerative control, but this

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[1] There is also a certain amount of coupling between oscillator and signal circuits even at low frequencies as a result of the fact that the voltage on the signal grid affects the current flowing to the oscillator grid G_2. See Paul W. Klipsch, Suppression of Interlocking in First Detector Circuits, *Proc. I.R.E.*, vol. 22, p. 699, June, 1934.

effect is small because the reactance change amounts to only a few ohms and so is small compared with the large reactances in the tuned circuit. The change of resistance resulting from regeneration is much more important because the resistance of the tuned input circuit is so low that a few ohms added or subtracted represents a large percentage variation. When the energy is fed back in the proper phase to reinforce the applied signal, the effect is to neutralize a part of the resistance of the tuned input circuit. This raises the effective Q and so increases the resonant rise of voltage (which is equivalent to added amplification), as well as making the selectivity greater.

When the regeneration is carried as far as possible (*i.e.*, until the effective resistance of the input circuit approaches zero), the resulting amplification is very great for extremely weak signals, and still large but less for strong signals.[1]

While representing an inexpensive means of obtaining radio-frequency amplification, regeneration has several disadvantages. In the first place regenerative amplification is obtained by lowering the effective resistance of a tuned circuit, and, since this also greatly increases the selectivity, regeneration tends to suppress the higher side-band frequencies contained in the signal. In the second place the adjustments required to give satisfactory regenerative amplification also depend upon the frequency of the signal so that it is necessary to readjust the regeneration controls for every new signal. Furthermore the adjustments required to give appreciable regenerative action are rather critical, and a certain amount of skill is required to carry them out properly. Finally, when the regenerative action is carried to the point where the circuit resistance is completely neutralized and becomes negative, as will inevitably occur from time to time as the result of accidental improper adjustments, oscillations will be set up which will heterodyne with any signal that may be present and produce annoying squeals. These disadvantages of regenerative amplification are so great that it is generally considered better practice to obtain radio-frequency amplification by the use of tuned radio-frequency amplifiers rather than by regeneration.

Oscillating Detectors.—When regeneration is increased to the point where the resistance of the resonant circuit is completely neutralized,

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[1] This dependence upon signal voltage arises because the third-order curvature of the tube characteristic causes the effective plate resistance of the tube to be slightly greater for large signals than for small, thus reducing the regeneration for large signals. Analysis shows that, when the regeneration is made as great as possible without oscillation in the absence of a signal, the amplification is inversely proportional to the two-thirds power of the signal voltage and directly proportional to the response obtained when no regeneration is present See Balth van der Pol, The Effect of Regeneration on the Received Signal Strength, *Proc. I.R.E* , vol. 17, p. 339, February, 1929

there will be set up oscillations which will heterodyne with any signal currents in the resonant circuit. The resultant beats are rectified by the detector and cause difference-frequency currents to appear in the detector output. The oscillating detector therefore acts as a heterodyne detector in which the detector tube generates the heterodyne oscillations, as well as functioning as a rectifier. The circuits used in oscillating detectors are the same as those employed for regenerative detectors, the only difference being that the regeneration is increased to the point where oscillations are produced. Grid-leak power rectification is always employed in oscillating detectors because of its high sensitivity and because it automatically supplies the proper grid bias for the oscillations.

The oscillating detector is used extensively in the reception of code signals, particularly short-wave code signals. Compared with a separate heterodyne for such purposes, the arrangement has the advantage of much greater sensitivity[1] and of being simpler to adjust. Thus, when the local oscillations have a frequency suitable for heterodyning the code signal to an audio-frequency such as 1000 cycles, the input circuit is automatically tuned approximately to resonance with the incoming signal. The oscillating detector arrangement is not suitable for use with superheterodyne receivers, however, and is also usually avoided in code reception of the lower radio frequencies. This is because under such conditions the difference frequency is a large percentage of the signal frequency, so that when the oscillations have the proper frequency the input circuit is very considerably detuned from the signal frequency.

The great sensitivity of the oscillating detector is a result of the large regenerative amplification that the signal undergoes before being rectified. When no signal is present, the oscillations have an amplitude such that the effective plate resistance of the tube has a value for which the regeneration exactly neutralizes the resistance of the resonant circuit. When this condition exists, the regenerative amplification to a superimposed oscillation is very great because the situation is much the same as that which exists in an ordinary regenerative detector adjusted to give the maximum possible regeneration. The difference in the two cases, however, is that with the regenerative detector this adjustment is very critical and impossible to maintain, whereas in the oscillating detector the oscillations automatically assume an amplitude that picks out this critical condition and maintains it with complete stability.

The regenerative amplification which the signal undergoes in an oscillating detector can be analyzed by considering that the signal repre-

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[1] Thus a simple oscillating detector will make practically any short-wave code signal that is above the noise level audible in a telephone receiver. Effective amplifications as high as 15,000 are indicated under optimum conditions. See H. A. Robinson, Regenerative Detectors, *QST*, vol. 17, p. 26, February, 1933.

sents a voltage that is induced in the resonant circuit in addition to the voltage induced by the feedback from the plate circuit. The phase of the signal with respect to the oscillation changes from aiding to opposition at a rate corresponding to the difference frequency, as in the case of any heterodyne signal. To a first-order approximation the variation in the amplitude of the resultant wave applied to the grid of the tube acts as though there were no signal voltage applied to the detector, but rather as though the regeneration of the oscillating detector were alternately decreased and increased from its actual value at a rate corresponding to the beat frequency. The oscillating detector hence has its greatest sensitivity when a small change in the regeneration will produce a large change in the amplitude of the generated oscillations. This condition is always realized when the regeneration has the smallest value at which oscillations will exist and when the resonant circuit has the highest possible Q (*i.e.*, lowest possible actual resistance).

Typical oscillating-detector circuit arrangements are illustrated in Fig. 253. Pentode tubes are generally used, with the regeneration control obtained by varying either the screen voltage or the electrostatic or magnetic coupling between input and plate circuits. When the regeneration control is applied to the screen voltage, the circuit design should be such that oscillations will stop when the screen is of the order of 20 to 40 volts. If the stopping point is at higher potentials, the oscillations start and stop with an annoying thump, whereas, if the critical point is a lower voltage, the conversion efficiency of the arrangement as a detector is low because of the small plate current.

When the oscillating detector employs a triode tube, trouble is sometimes encountered from a sustained audio-frequency sound which occurs when the adjustment is such that oscillations are just barely maintained. This is known as "threshhold" or "fringe" howl, and is to be avoided since it occurs under conditions for which the oscillating detector is most sensitive. Threshhold howl may occur in grid-leak arrangements when the audio-frequency load impedance in the plate circuit of the triode is inductive, and it can be cured either by using resistance coupling or by shunting the inductive load with a sufficiently low resistance. Threshhold howl does not ordinarily occur when pentode tubes are employed.[1]

90. Superregenerative Detectors.[2]—A superregenerative detector is a regenerative detector which is varied from an oscillatory to a non-oscil-

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[1] The mechanism of threshhold howl is described by L. S. B. Alder, Threshhold Howl in Reaction Receivers, *Exp. Wireless and Wireless Eng.*, vol 7, p. 197, April, 1930.

[2] For further information on superregeneration, see Hikosaburo Ataka, On Superregeneration of an Ultra-short Wave Receiver, *Proc. I.R E.*, vol. 23, p. 841, August, 1935; D. Grimes and W. S Barden, A Study of Superregeneration, *Electronics*, p. 42,

lating condition at a low radio-frequency rate. During the oscillatory interval, oscillations build up, only to be suppressed, or "quenched," and the resulting action is such that with proper adjustment an applied signal is amplified enormously before detection. A typical superregenerative circuit is shown in Fig. 254, and consists of a tube arranged to regenerate in the manner shown in Fig. 253*c*, but supplied with a plate voltage that is a low radio frequency, such as 25 kc. Oscillations then build up during the half cycles when the plate is positive, but die out (*i.e.*, are quenched) during the time the plate is negative. For proper operation the oscillations must die out completely before they start to built up, which is equivalent to saying that the average resistance of the circuit must be positive.

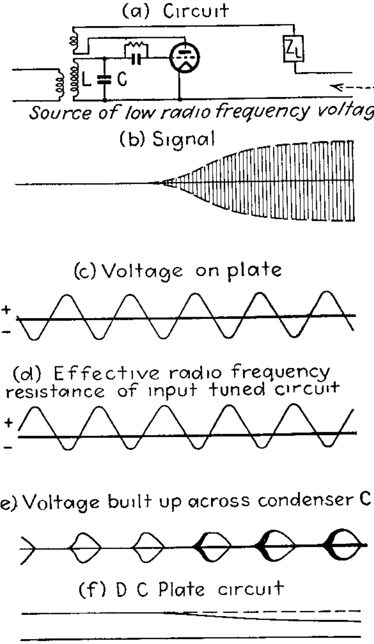


FIG. 254.—Simple superregenerative circuit, together with details showing the mechanism by which superregenerative amplification is obtained.

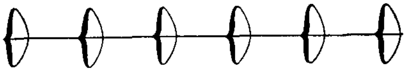
When no signal is present, the initial pulse that starts the building up of oscillations is supplied by thermal agitation, shot effect, etc., and the resulting oscillations are as illustrated to the left in Fig. 254*e*. The area under the envelope of the curve of oscillations depends upon the amplitude of the initiating pulse, and, since this is a chance factor of thermal agitation, etc., the areas under successive envelopes differ in a random manner, and the rectified output contains a characteristic hiss. However, upon the application of a signal that has a greater amplitude than the random voltages, the signal then becomes the initiating pulse, thereby suppressing the characteristic hiss and causing the building-up process to get under way faster, as shown to the right in Fig. 254*e*, where the shaded area represents the difference caused by the presence of the signal. Inasmuch as the initiating pulse, and hence the time required to reach full amplitude, is proportional to the amplitude of the signal, the shaded area in Fig. 254*e* will vary with the amplitude of the signal, and hence will reproduce in a rough sort of way the modulation of the signal.

February, 1934; Edwin H. Armstrong, Some Recent Developments of Regenerative Circuits, *Proc. I.R.E.*, vol. 10, p. 244, August, 1922; M. G. Scroggie, The Superregenerative Receiver, *Wireless Eng.*, vol. 13, p. 581, November, 1936.

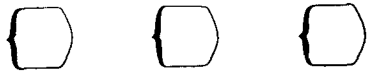
The output of the superregenerative detector is obtained by rectifying the oscillations that are built up across the tuned circuit, using a grid-leak condenser combination as shown in Fig. 254*a*. The bias voltage developed across this combination will be proportional to the average amplitude of the oscillations, and so will vary in accordance with the shaded area as illustrated in Fig. 254*f*, causing the plate current to be reduced by the presence of a signal by an amount that varies in accordance with the modulation envelope.

(a) Signal

(b) Proper quenching frequency



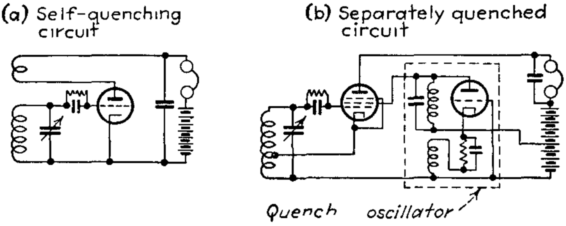
(c) Quenching frequency too low



(d) Quenching frequency too high

FIG. 255 —Oscillograms showing effect of quench frequency upon output of superregenerative detector The shaded area represents the output caused by the presence of a signal.

In order to obtain best results with a superregenerative detector it is necessary to have a proper balance between the circuit proportions and the amplitude and frequency of the quenching oscillation. The effect of the quenching frequency is illustrated in Fig. 255. Starting with low quenching frequencies, it is seen that at first increasing the quenching frequency increases the number of times the oscillations build up in a given length of time and therefore increases the total of all the shaded areas almost in direct proportion to the quenching frequency. The output and hence the sensitivity therefore increase with quenching frequency, until an optimum value is reached such that the oscillations just have time to approach full amplitude when they are quenched. With quenching frequencies higher than this, the width of the shaded area decreases and there is a tendency for the oscillations to be quenched before they have time to build up to full amplitude, so that, although the number of shaded areas per second increases, the size of each area is so diminished that the net result is a considerable loss in sensitivity.



(a) Self-quenching circuit

(b) Separately quenched circuit

FIG 256 —Circuits of typical superregenerative detectors.

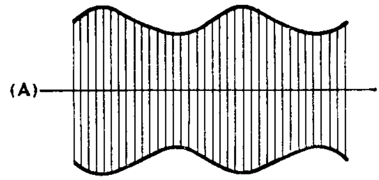
Two additional circuit arrangements for producing superregeneration are illustrated in Fig. 256. The arrangement at (*a*) is particularly useful because it requires no special circuits or auxiliary quenching oscillator. This circuit obtains the quenching action by operating the circuit so that interrupted oscillations are produced by the mechanism discussed in Sec. 66, thereby making the arrangement self-quenching. The interrupted oscillations can be obtained by use of a high grid-leak resistance, a relatively large grid-condenser capacity, and sufficient regeneration to make the circuit strongly oscillatory. The frequency of interruption can be controlled by varying either the regeneration or the grid-leak resistance.

A properly adjusted superregenerative detector is characterized by extremely great sensitivity. A single tube is capable of giving an audible output with signals that have an amplitude comparable with the thermal agitation voltages present in the input circuit. Experience with superregenerative detectors also indicates that they are much less susceptible to such interference as ignition noises than are most receivers. The reason for this appears to be that there is an inherent limiting action contained in the mechanism of operation whereby very loud signals produce only slightly more output than do weak signals. As a consequence strong intermittent noise voltages produce outputs only slightly larger than those obtained from weak signals.

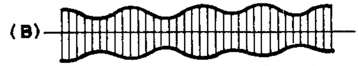
At the same time the superregenerative detector has a number of limitations. In the first place, a characteristic hiss is always present in the absence of an applied signal, and, though this hiss disappears in the presence of a signal, it makes superregeneration impracticable for such purposes as broadcast receivers. A superregenerative receiver also possesses rather poor selectivity, this being necessarily true because of the large number of side-band frequency components produced by the quenching action. The principal practical use of superregeneration has been in the reception of signals of such high frequency that ordinary methods of amplification cannot be employed.

91. Detector Output When the Applied Signal Consists of Two Modulated Waves.—Circumstances commonly arise where in addition to the desired signal there is also a relatively weak but not negligible interfering signal applied to the detector input. The most important effects produced under such conditions are: (1) the suppression of the weaker signal when a linear detector is employed and when the difference in carrier frequencies of the two signals is above audibility; (2) an audible beat note representing the difference frequency between the two carriers when these differ in frequency by an amount lying in the audible range; (3) a flutter occurring when the carrier frequencies are almost but not exactly in synchronism; and (4) distortion occurring when the carriers are of identical frequency and when both desired and undesired stations are broadcasting the same program.

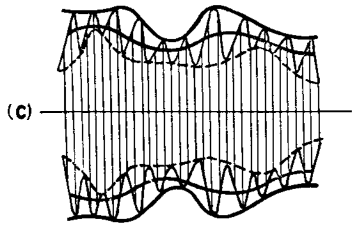
When two modulated signals of unequal amplitudes and of carrier frequencies that are so different as to produce an inaudible beat frequency are simultaneously applied to the input of a linear rectifier, it is found that the weaker of the two signals is not rectified. This is because under these conditions the envelope of the combined signal is as shown in Fig. 257, having a principal modulation representing the desired modulation and a minor variation corresponding to the inaudible beat frequency between the two carriers. This minor variation is modulated in accordance with the modulation of the undesired carrier, but upon *linear* rectification the detector output follows the modulation envelope and hence contains no component that follows the modulation of the undesired weaker signal. *This suppression of the weaker modulation is equivalent to an increase in the effective selectivity and represents an important property of a linear detector.*[1] In order that the suppression of the weaker signal may be complete, it is necessary that the strong signal be considerably larger than the weaker and that the detector be exactly linear. With ordinary rectifiers the suppression becomes very pronounced when the ratio of signal amplitudes exceeds 2 to 1. This suppression of the weaker signal does not occur in the case of square-law detectors.



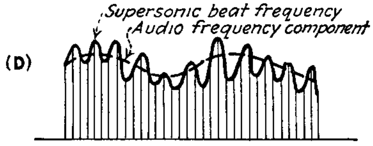
Desired Signal



Undesired Weaker Signal



Desired and Undesired Signals Superimposed



Wave (C) After Linear Rectification

FIG. 257.—Wave forms obtained in the linear detection of a signal consisting of a weak modulated wave superimposed upon a strong modulated wave The rectified output of the linear detector is seen to contain no component varying at the modulation frequency of the weaker signal

When the difference between the carrier frequencies of the desired and undesired signals is in the audible range, a number of undesired

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[1] For further information and details of the method of analyzing this phenomenon, see R. T. Beatty, Apparent Demodulation of a Weak Station by a Stronger One, *Exp. Wireless and Wireless Eng.*, vol. 5, p. 300, June, 1928; S. Butterworth, Note on the Apparent Demodulation of a Weak Station by a Stronger One, *Exp. Wireless and Wireless Eng.*, vol. 6, p. 619, November, 1929; E. V. Appleton and D. Boohariwalla, The Mutual Interference of Wireless Signals in Simultaneous Detection, *Exp. Wireless and Wireless Eng.*, vol. 9, p. 136, March, 1932.

components of audible frequency appear in the output of both square-law and linear detectors. The component having the largest amplitude is the difference frequency between the two carriers, and this is the most disturbing component when it exceeds 100 to 200 cycles.

When the frequencies of the two carriers differ by less than about 50 cycles, the most disturbing components in the output are the difference frequencies formed by the carrier of the strong or desired signal heterodyning with the side-band frequencies of the weaker or undesired signal to produce what can be termed *side-band noise.* When the carrier frequencies differ by only a few cycles a second, this side-band noise gives rise to the characteristic flutter commonly heard when two or more broadcast stations are simultaneously transmitting on approximately the same frequency. When the two carriers are both weak enough so that there is a background of noise, the noise level in the detector output will also flutter at a frequency corresponding to the difference frequency between the two carriers, and may in some cases produce an effect more annoying than the side-band noise.

In the event that the two signals come from stations which have their carriers synchronized and which are modulated with identical programs, the detector output will not ordinarily represent a distortionless reproduction of the original modulation unless one of the carrier amplitudes is much weaker than the other. This is because the relative phase with which the two carriers and their respective side-band components combine in the detector input depends upon the distance to the transmitter, time differences in the transmission of the program, and the side-band frequency involved. The result is that, when the carrier amplitudes are of approximately the same order of magnitude, certain side-band frequencies will tend to cancel while others will be reinforced; furthermore at certain locations the two carriers will also tend to cancel and thereby distort the envelope of the wave applied to the detector input. In order for distortion of this sort to be imperceptible under the worst practical conditions, it is necessary that one carrier have an amplitude at least four times that of the other carrier.

The exact nature of these effects which occur when the two carrier frequencies differ by only a small amount, or are synchronized, depends upon whether a linear or square-law rectifier is used, upon the relative amplitudes of the two carriers, and upon their degrees of modulation. The exact analysis is too involved to be presented here, but is to be found in the literature.[1]

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[1] The most extensive work on this subject is that of C. B. Aiken. The method of analysis that he has employed in attacking the problem, as well as the essential results, are contained in the following papers: Charles B. Aiken, Theory of the Detection of Two Modulated Waves by a Linear Rectifier, *Proc. I.R.E.*, vol. 21, p. 601, April,