# ELECTRONIC DESIGNERS' HANDBOOK

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ing resistance is constant and is typically 10 to 30 ohms for silicon diodes. It prevents $C_b$ from being tuned out by an external reactance.

**7.10. Superregenerative Receivers.** A superregenerative receiver is an r-f amplifier or plate detector having sufficient positive feedback to cause oscillation. The receiver is caused to go in and out of oscillation by a control signal known as the quench signal. Typical quench-signal frequencies are between 10 kc and 1 Mc. Very high gains are possible. A one-tube circuit is capable of detecting the noise voltage existing at the tuned circuit input. The three possible modes of operation are (1) separate quenching, logarithmic mode, (2) separate quenching, linear mode, and (3) self-quenched mode.

*7.10a. Logarithmic Mode.* A schematic of a superregenerative detector is shown in Fig. 7.106. The grid circuit is resonant at the desired signal frequency and is coupled to the antenna or signal source as shown. The mutual coupling between the plate coil and grid circuit is sufficient to allow oscillations to build up when the grid bias is raised above the cutoff value. The fixed grid bias $E_{cc}$ is made greater than cutoff, and a control voltage is superimposed on the grid bias which periodically decreases the bias thereby permitting oscillations to start building up in the circuit. When the quench signal returns the grid bias sufficiently negative to stop the tube from conducting, the oscillations in the grid-tuned circuit decay exponentially. The equivalent grid circuit of the superregenerative detector is shown in Fig. 7.107. In the absence of the quench voltage, the circuit consists of $C$ in parallel with $L$ having some positive series resistance $R_L$. During the interval that the quench voltage causes the tube to conduct, the mutual coupling between the plate and grid circuits effectively introduces negative resistance $R_f$ in series with $L$. The instantaneous voltage $e_c$ across $C$ is given by

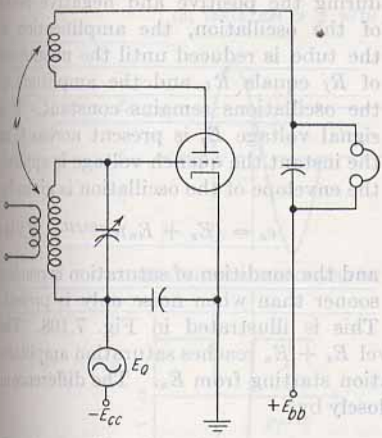


Fig. 7.106. Circuit of superregenerative detector.

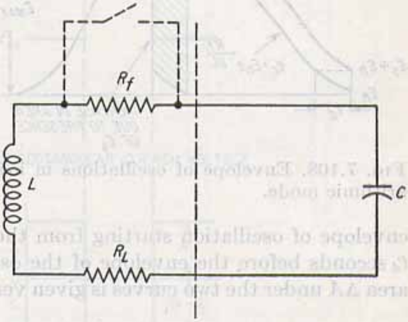


Fig. 7.107. Equivalent superregenerative detector resonant circuit.

$$\boxed{e_c = Ee^{-Rt/2L} \cos \omega_o t} \tag{7.242}$$

where $E$ = voltage across $C$ at time $t = 0$
$R$ = net circuit resistance, $R = R_L - R_f$
$\omega_o$ = resonant frequency of circuit $= \sqrt{\dfrac{1}{LC} - \left(\dfrac{R}{2L}\right)^2}$

At all times there is a voltage present across $C$ due to thermal noise, atmospheric noise, etc. Without the presence of the quench voltage, these voltages exponentially decay at a rate determined by the $Q$ of the circuit. When the quench voltage causes the tube to conduct, however, the feedback resistance $R_f$ exceeds $R_L$ in magnitude and the exponent in Eq. (7.242) becomes positive. As a result, the voltage across $C$ exponentially increases from its value at the instant the quench voltage is applied until a state of equilibrium is reached. The frequency of the exponentially increasing oscillation is $\omega_o$. The amplitude of the envelope of the oscillation in the interval before grid and/or plate current saturation is reached is given by

$$e_c = E_n e^{-Rt/2L} \tag{7.243}$$

where $E_n$ = noise voltage across $C$ at $t = 0$

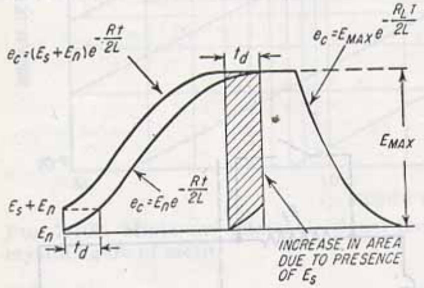


FIG. 7.108. Envelope of oscillations in logarithmic mode.

When the amplitude of the oscillations becomes large enough to drive the grid into the regions of grid conduction and cutoff during the positive and negative peaks of the oscillation, the amplification of the tube is reduced until the magnitude of $R_f$ equals $R_L$ and the amplitude of the oscillations remains constant. If a signal voltage $E_s$ is present across $C$ at the instant the quench voltage is applied, the envelope of the oscillation is given by

$$e_c = (E_s + E_n)e^{-Rt/2L} \tag{7.244}$$

and the condition of saturation is reached sooner than when noise only is present. This is illustrated in Fig. 7.108. The envelope of oscillation starting from the level $E_s + E_n$ reaches saturation amplitude $t_d$ seconds before the envelope of the oscillation starting from $E_n$. The difference in area $\Delta A$ under the two curves is given very closely by

$$\Delta A = t_d E_{\max} \tag{7.245}$$

where $E_{\max}$ = amplitude of oscillation when equilibrium has been attained (see Fig. 7.108)

The time interval $t_d$ is given by

$$t_d = -\frac{2L}{R}\log_e\frac{E_s + E_n}{E_n} \tag{7.246}$$

The increase $\Delta E$ in the average voltage across $C$ due to the presence of a signal is

$$\boxed{\Delta E = -\frac{2Lf_Q E_{\max}}{R}\log_e\frac{E_s + E_n}{E_n}} \tag{7.247}$$

where $f_Q$ = frequency of applied quench voltage

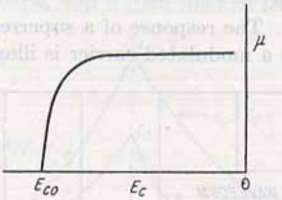
The quantity $f_Q E_{\max} 2L/R$ can be made equal to several volts. Therefore, even though $E_s$ may be only a few microvolts, if the noise voltage is the same order of magnitude, the gain of the stage will be in the order of a million.

*1. Considerations for Maximizing the Gain in Logarithmic Mode Operation.* The gain of a superregenerative detector operating in the logarithmic mode can be maximized by making the terms $E_{\max}$, $2L/R$, and $f_Q$ as large as possible. However, the terms are interdependent and must be considered simultaneously. General considerations are:

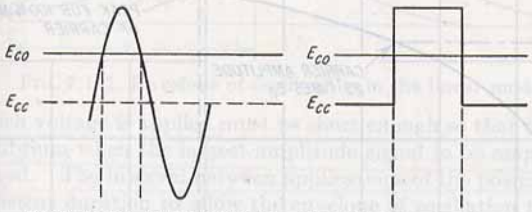
*a.* As the magnitude of $2L/R$ is increased, the rate of increase of the oscillations is reduced and the period for which the quench voltage must be applied is increased.

b. As $E_{\max}$ is increased, the interval required for the oscillation buildup to the level of $E_{\max}$ and the interval required for the oscillation to decay to a level lower than the originating signal are increased.

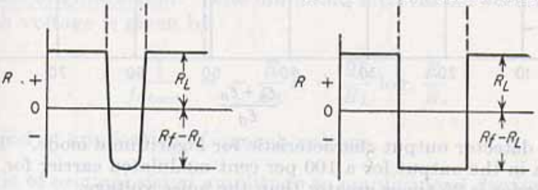
c. The higher the $Q$ of the resonant circuit itself, i.e., the higher $\omega_0 L/R_L$, the longer the decay interval.



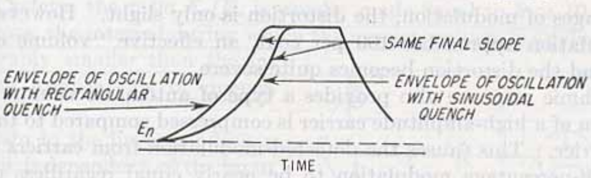
(a) VARIATION OF $\mu$ WITH $E_c$ FOR TYPICAL TRIODE



(b) SINUSOIDAL QUENCH VOLTAGE (c) RECTANGULAR QUENCH VOLTAGE



(d) VARIATION IN NET CIRCUIT RESISTANCE WITH QUENCH VOLTAGE



(e) OSCILLATION ENVELOPES FOR SINUSOIDAL AND RECTANGULAR QUENCH VOLTAGES

FIG. 7.109. Effect of quench-voltage waveshape upon envelope of oscillation buildup.

d. The longer the buildup and decay periods, the lower must be the maximum value f the quench frequency.

e. The quench frequency $f_Q$ must be enough higher than the desired signal modulaon frequencies to allow effective filtering of $f_Q$ from the output, and in any case $f_Q$ ust be at least twice the highest modulation frequency to be detected.

f. The gain can be increased by reducing $R$ [see Eq. (7.247)]. This can be accomished by either decreasing the amount of feedback or by reducing the $Q$ of the sonant circuit itself. The net effective circuit resistance $R$ must be maintained gative, however, in order for the circuit to oscillate.

2. *Quench-voltage Waveform.* The waveform of the quench voltage is usually ctangular or sinusoidal. The gain with a sinusoidal quench voltage is slightly

greater than with a rectangular quench voltage because of the fact that the net circuit resistance $R$ requires a longer period to change from its initial value of $R_L$ to the final value $R_L - R_f$ if the quench voltage has a slow rate of rise. A low negative value of $R$ causes the oscillation to build up slowly so that the time interval $t_d$ [see Eq. (7.246)] in Fig. 7.108 will be greater for sinusoidal quench than for rectangular quench. This effect is illustrated in Fig. 7.109.

*3. Modulation Reproduction.* The response of a superregenerative receiver operating in the logarithmic mode to a modulated carrier is illustrated in Fig. 7.110. For

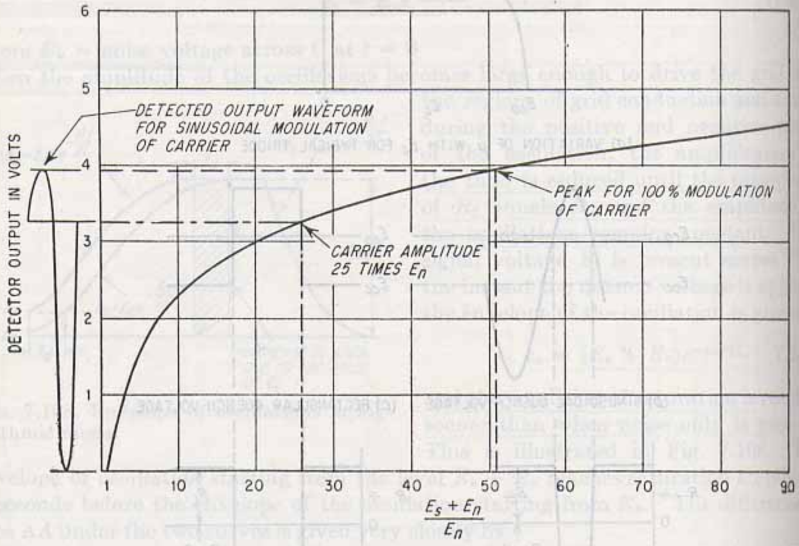


FIG. 7.110. Typical detector output characteristic for logarithmic mode. The figure illustrates the distortion in the output for a 100 per cent modulated carrier for the case where the unmodulated carrier is 25 times greater than the noise voltage.

small percentages of modulation, the distortion is only slight. However, as the percentage modulation approaches 100 per cent, an effective "volume expansion" is experienced and the distortion becomes quite severe.

The logarithmic response also provides a type of automatic volume control since the modulation of a high-amplitude carrier is compressed compared to that of a lower-amplitude carrier. This causes the detected modulation from carriers which have a constant small-percentage modulation to be nearly equal regardless of the carrier amplitude.

*7.10b. Linear Mode.* The linear mode of operation is shown in Fig. 7.111. The length of the period during which the quench voltage is applied is reduced so that the tube does not reach equilibrium before the quench voltage is removed. The average value of grid voltage during one quench cycle is greater when a signal is present than when noise alone is present since the envelope of oscillations increases exponentially from a higher initial voltage. The envelope of the oscillations has, therefore, increased to a higher voltage when the quench voltage is removed and decays to zero from this higher voltage. If it is assumed that the net circuit resistance $R$ is a constant for the interval that the quench voltage causes the tube to conduct, the voltage gain $A$ for the linear mode can be determined from

$$A = \frac{\Delta E}{E_s} = f_Q \left[ \left( -\frac{2L}{R} + \frac{2L}{R_L} \right) e^{-Rt_1/2L} + \frac{2L}{R} - \frac{2L}{R_L} e^{[-Rt_1 + R_L(t_1 - t_2)]/2L} \right] \qquad (7.248)$$

where $t_1$ = time interval during which quench voltage is applied

$t_2 = 1/f_Q$

$\Delta E$ = change in average voltage across $C$ due to presence of $E_s$

Maximum gain is obtained in the linear mode by having a high value of $-R/2L$, that is, large positive feedback, and a high quench frequency. The interval during which the quench voltage is applied must be short enough so that the oscillation does not reach equilibrium when the largest amplitude signal to be amplified without distortion is received. The interval between applications of the positive quench voltage must be of sufficient duration to allow the envelope of oscillation to decay to a level below that of the original signal. The minimum interval between applications of the positive quench voltage is given by

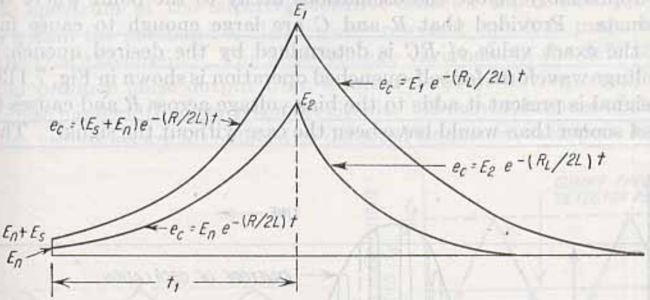


FIG. 7.111. Envelope of oscillations in the linear mode.

$$\frac{1}{f_{Q(\max)}} = -\frac{R}{R_L}t_1 + \frac{2L}{R_L}\log_e\frac{E_s}{E_o} \qquad (7.249)$$

where $t_1$ = period of application of quench voltage

$\frac{E_s}{E_o}$ = ratio of original signal amplitude to amplitude of decayed oscillations

As a factor of safety, the ratio $E_s/E_o$ is usually made equal to 5 or 10. Because of the above factors, the interval during which the quench voltage is applied is normally made considerably smaller than the interval between applications of quench voltage.

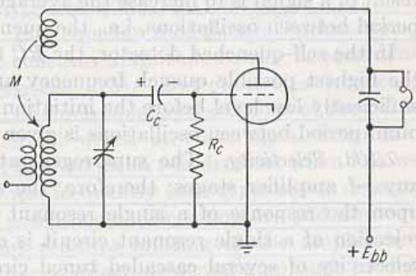


FIG. 7.112. Circuit of a self-quenched superregenerative detector.

Since the gain in the linear mode is a constant and is independent of the input signal amplitude, the linear mode superregenerative detector reproduces modulation with a minimum of distortion.

*7.10c. Self-quenched Detector.* If a superregenerative detector is connected as shown in Fig. 7.112, it will operate in a self-quenched fashion. Oscillations initially build up from the level of noise within the tuned circuit until the grid is driven into the positive grid region during the peaks of the oscillations. Blocking capacitor $C$ is then charged with the polarity shown in Fig. 7.112 by the flow of grid current during the positive peaks of the oscillations.

$R$ is made large enough so that the bias voltage created by the current flowing through $R$ in discharging $C$ is great enough that the tube is cut off for such a large portion of each oscillation cycle that it cannot overcome the circuit losses during the rest of the cycle. After building up exponentially from noise to the level where grid current flows during the peaks of oscillation, the oscillation decays rather gradually until the instantaneous grid bias is always greater than cutoff for the tube. At this point, the oscillations decay exponentially. The value of $C$ must be large enough that the time constant $RC$ is sufficient to prevent the bias voltage from decreasing appreciably before the oscillations decay to the point where the tube no longer conducts. Provided that $R$ and $C$ are large enough to cause intermittent oscillation, the exact value of $RC$ is determined by the desired quench frequency. The grid-voltage waveform for self-quenched operation is shown in Fig. 7.113.

When a signal is present it adds to the bias voltage across $R$ and causes the oscillations to start sooner than would have been the case without the signal. The envelope of the oscillation is the same each time regardless of the presence of a signal, so that the result of a signal is to increase the average current through the tube by decreasing the period between oscillations, i.e., the quench frequency is increased.

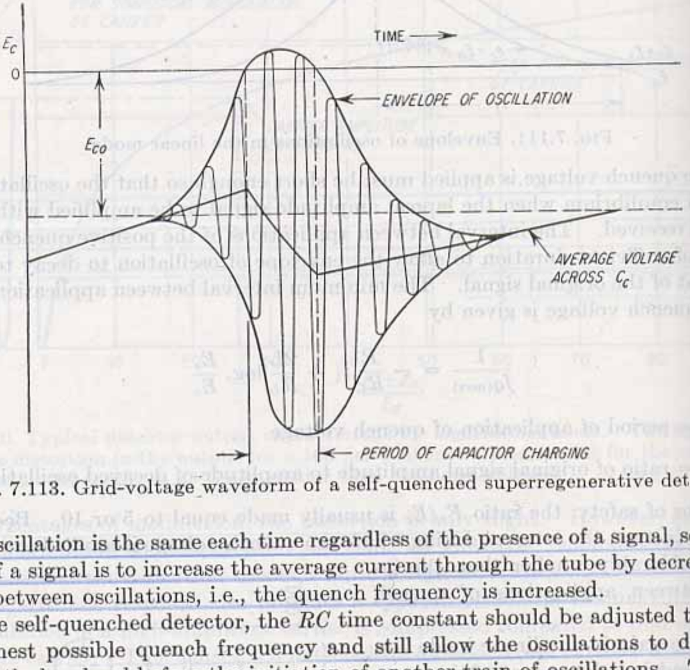


FIG. 7.113. Grid-voltage waveform of a self-quenched superregenerative detector.

In the self-quenched detector, the $RC$ time constant should be adjusted to provide the highest possible quench frequency and still allow the oscillations to decay to a sufficiently low level before the initiation of another train of oscillations. The minimum period between oscillations is given by Eq. (7.249).

*7.10d. Selectivity.* The superregenerative detector is normally not preceded by any r-f amplifier stages; therefore, the selectivity of such a detector is dependent upon the response of a single resonant circuit. The selectivity or adjacent band rejection of a single resonant circuit is considerably poorer than the corresponding selectivity of several cascaded tuned circuits having the same over-all −3-db bandwidth (see Fig. 7.13).

However, the effective $Q$ of the detector resonant circuit is considerably higher than $\omega L/R_L$. As the quench voltage is applied and the grid bias reaches cutoff, the tube begins to amplify, but the grid bias must increase to a value somewhat above cutoff before the tube $\mu$ is high enough to cause the net circuit resistance to become negative and for oscillations to start. During the interval when the grid bias is between cutoff and the value where oscillations start, the net circuit resistance is positive but decreasing from $R_L$ to $O$ and the effective $Q$ of the resonant circuit is increasing. This regenerative period increases the $Q$ of the circuit several times.

*7.10e. Noise in Superregenerative Detectors.* The superregenerative detector detects the presence of a carrier and the modulation of that carrier by "sampling" the signal at the quench frequency rate. The result is that the detected modulation of a carrier varies in accordance with the actual modulation of the carrier as shown in Fig. 7.114. The highest possible detection frequency is $f_Q/2$, and all higher modulation frequencies are converted to some frequency between zero and $f_Q/2$.

The noise spectrum of the superregenerative-detector input circuit contains all frequencies within the passband of the detector resonant circuit in proportions determined by the $Q$ of the circuit. The noise voltage variations in the detector resonant circuit would produce noise output from a linear detector having components from zero to the noise bandwidth of the resonant circuit. However, because of the sampling process, these variations are all reduced to detected frequency variations between zero and $f_Q/2$ in this type of detector. This is illustrated in Fig. 7.115. Consequently, the noise output of the detector in the region of zero to $f_Q/2$ is considerably higher than for other detectors. The noise voltage per unit bandwidth at the detector output is inversely proportional to the $Q$ of the resonant circuit and the quench frequency.

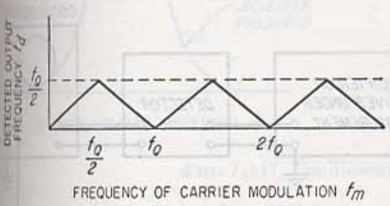


FIG. 7.114. Detected modulation frequency versus carrier modulation frequency for a superregenerative detector.

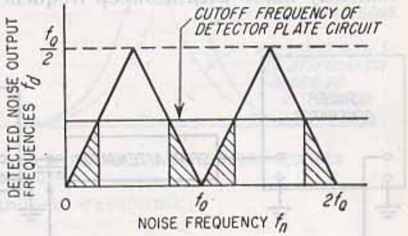


FIG. 7.115. Noise output from a superregenerative detector.

*7.10f. Pulse Reception.* The superregenerative receiver can be used for pulse reception by providing adequate bandwidth in the r-f circuit and by raising the quench frequency so that one or more oscillation buildups occur within the duration of the shortest pulse to be received.

The discharge time constant of the detector circuit must also be minimized to provide adequate resolution between successive pulses.

**7.11. Frequency-modulation Receivers.** In frequency modulation, information is transmitted by varying the frequency of a constant amplitude carrier in accordance with the intelligence to be transmitted (see Sec. 5.5). Detection of a frequency-modulated signal consists of the conversion of the frequency variations of the carrier to amplitude variations. Although any circuit which provides signal attenuation which varies as a function of frequency can be used as an f-m detector when followed by a conventional amplitude detector, the most frequently used types of f-m detectors are the Foster-Seeley discriminator, the gated-beam discriminator, and the ratio detector.[1] The Foster-Seeley discriminator requires limiting of the amplitude of the received carrier prior to detection in order to reject incidental amplitude modulation from the output. The gated-beam discriminator utilizing the 6BN6 tube provides limiting of the signal amplitude within the tube itself. The ratio detector circuit also provides good rejection of any amplitude modulation.

Frequency-modulation receivers are identical to other receiver types designed for amplitude modulation except for the detector circuit. Superheterodyne receivers are

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[1] The first two of the above detectors are discussed in Sec. 7.6e. For details of the ratio detector see S. W. Seeley, The Ratio Detector, *RCA Rev.*, vol. 8, pp. 201–236, June, 1947.