Regenerative Detectors

What We Get from Them—How to Get More

By H. A. Robinson, W3LW*

TO THE average radio amateur the subject of regeneration and its usual application in the regenerative detector might at first glance appear to be one about which a great deal is known. Actually, such is not the case and although we have been employing regenerative circuits and detectors for years, our store of definite information concerning their operation is very meager. The reason for this lack of exact performance data on this subject is apparent when one considers that only recently refinements in signal generator and measuring equipment have permitted such measurements to be made with any degree of precision. To be sure, we have all understood the fundamental relations of the principle of regeneration and amateur radio has made great advances by use of the relatively enormous amplification obtained by feeding back into the grid circuit a portion of the amplified energy in the plate circuit. However, how many operators really have quantitative data on the amplification of a regenerative circuit or the resultant selectivity, the effect of ticklers, tube characteristics, signal level, etc?

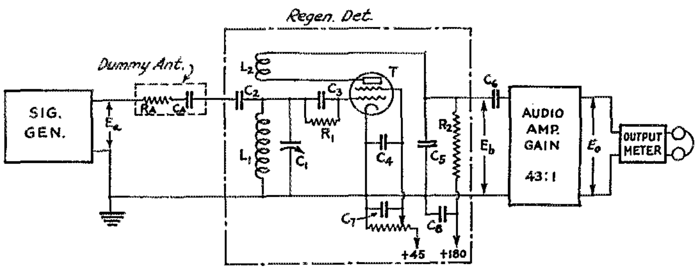

FIG. 1 — CIRCUIT USED FOR THE EXPERIMENTAL INVESTIGATION

C_A — 100 μμfd.
C_1 — 10 to 125 μμfd.
C_2 — 7 μμfd.
C_3 — 100 μμfd.
C_4 — .001 μfd.
C_5 — 150 μμfd.
C_6 — .006 μfd.
C_7 — 0.5 μfd.
C_8 — 0.5 μfd.
R_A — 100 ohms.
R_1 — 100,000 ohms to 5 megohms.
R_2 — 100,000 ohms.
T — Type '36 tube.
L_1 and L_2 — See Table II.

It is the purpose of this paper to present the results of an extended series of measurements of regenerative circuits and detectors. The diagram of Fig. 1 shows the experimental setup employed. The circuit elements for which no values are given are referred to in the text. Alternative circuit arrangements measured are shown in Fig. 2, including the screen-grid tickler circuit.

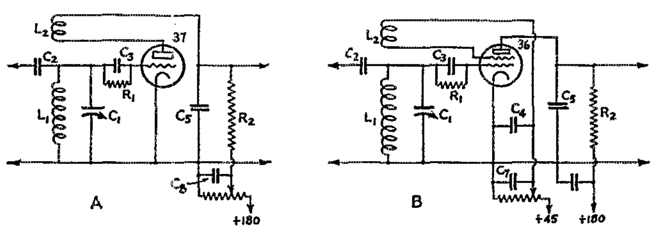

FIG. 2 — THE TYPICAL REGENERATIVE DETECTOR CIRCUITS STUDIED

The circuit constants correspond with those of Fig. 1.

REGENERATION AND SELECTIVITY

The problem of what *L-C* ratio of the tuned circuit will result in the best selectivity is of interest both in the regenerative and non-regenerative cases. From a theoretical standpoint the selective characteristics of a tuned circuit employed as shown in Fig. 1 or as a coupling impedance for an r.f. amplifier are given approximately[1] by the relation of Fig. 3. The curves of Fig. 4 plainly illustrate the effects of the *L-C* ratio as well as the r.f. resistance of the tuned circuit on the selective characteristics of a typical single tuned circuit. A fairly high *L-C* ratio (19.5×10^4) and low resistance coil resulted in the selectivity curve A, while B was obtained with an *L-C* ratio only one quarter that of A and a correspondingly lower r.f. resistance. The relation between the r.f. resistance and inductance is the determining factor and no general formula can be derived since so many factors such as coil shape, size and spacing of conductors, insulation and surrounding dielectric, are involved. The curves shown are based on a variation of r.f. resistance proportional to the three-halves power of the inductance. A variation of this order is verified by experiment.

The effect of changing the r.f. resistance of the

*Silver Lake Farm, Willow Grove, Pa.

[1] Approximations — (1) Antenna loosely coupled; C2 less than 10-μμfd. at 7000 kc. (2) Tuned circuit r.f. resistance low compared to reactance of circuit elements; r less than one-tenth X_L.

tuned circuit for a given *L-C* ratio can be surmised from the relation of Fig. 3, since only the impedance at resonance is affected. Decreasing the effective resistance of the tuned circuit, by improved coil design, looser input coupling or regeneration, results in a decided improvement in selectivity as shown by Curve C (Fig. 4) which is obtained with the same *L-C* ratio as Curve A but with a tuned circuit resistance only one-tenth as great.

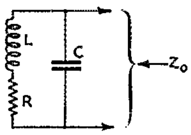

FIG. 3

Theoretically the selective characteristics of a tuned circuit are such that the impedance at resonant frequency

$$Z_o = \frac{X^2{}_L}{r}$$

while for frequencies more than 5% off resonance:

$$Z'_o = \frac{X_L\ X_C}{X_L - X_C} \text{ (neglecting sign)}$$

where $X_L = 2\pi f L$

and $X_C = \frac{1}{2\pi f C}$

are evaluated at the frequencies under consideration. The selectivity or relative response to signals off resonance is

$$\frac{Z'_o}{Z_o} \times 100\%$$

Experimentally determined selectivity curves obtained with the circuit arrangement of Fig. 1 are shown in Fig. 5. The tuned circuit was resonant at 7200 kc. for each curve. Curves 1 and 2 are typical selectivity curves for single tuned circuits without regeneration, the lower *L-C* ratio being somewhat more selective. (Tuned circuit data in Table II.) The dissymmetry at frequen-

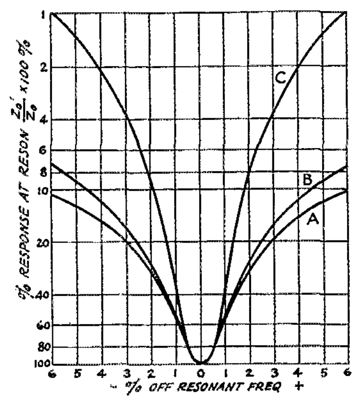

FIG. 4 — SINGLE CIRCUIT SELECTIVITY CURVES, NO REGENERATION. RESONANT FREQUENCY 7200 KC.

Curve	$L_{\mu h.}$	$C_{\mu\mu fd.}$	R_{ohms}	*Rel. Gain At Reson.*
A	9.75	50	6	1.4
B	4.88	100	2.1	1.0
C	9.75	50	0.6	14.0

TABLE I — EXPERIMENTAL DATA ON REGENERATION

7200 kc.

Tube Type	*Circuit Fig.*	*Det. Gain* E_b/E_a	*Sig. Level* E_a *volts*	*Tuned Circuit*	*Grid Leak Megs.*	*S.G. Volts*	*Remarks*
			30% Mod. Signal; Regen. Just below critical				
236	1	5,050	1.5	A	3	16.4	
"	"	3,400	"	"	"	12	Adjust Tickler
"	"	5,270	"	"	"	17.5	
"	"	7,750	"	"	"	31	
"	"	7,750	"	"	1	34	Increase Gridleak
"	"	7,750	"	"	3	31	
"	"	7,750	"	"	5	31	
"	"	7,750	"	"	3	30	Increase Sig. Level
"	"	7,900	7.5	"	"	30	
"	"	1,860	20.0	"	"	30	
"	"	7,750	1.5	"	"	31	Effect of Tuned Circuit
"	"	4,400	"	B	"	28.5	
"	"	4,830	"	C	"	32	
"	2B	4,850	"	"	"	30	S.G. Tickler
237	2A	1,650	"	"	"	—	Triode
236	1	9.2	"	A	"	30	Non Regen.
			C.W. Signal; Regen. Just above critical				
236	1	6,830	1.5	A	3	16.4	Adjust Tickler
"	"	13,500	"	"	"	23	
"	"	15,800	"	C	"	32	Plate Tickler
"	2B	15,800	"	"	"	30	S.G. Tickler
"	1	18,600	"	A	"	23	Sep. Het. Osc.

cies higher than that of resonance is a result of the capacitive input coupling which increases with frequency. Increasing degrees of regenerative feedback resulted in the sharpening of the selectivity curves as shown by the other curves of Fig. 5. The measure of the degree of regeneration employed in this case was the screen-grid voltage, as a percentage of its value at critical

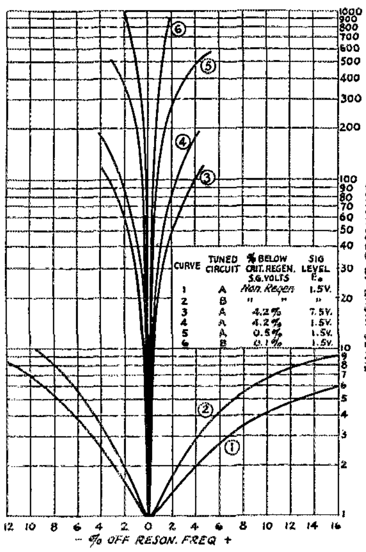

FIG. 5 — SELECTIVITY CURVES FOR REGENERATIVE CIRCUITS. RESONANT FREQUENCY 7200 KC.

regeneration (point of oscillation). The extreme degree of selectivity obtained at critical regeneration, when the effective resistance of the tuned circuit is practically reduced to zero, is clearly illustrated in Curve 6. This selectivity to a modulated signal still obtains when the regeneration control is slightly greater than critical and the circuit is self oscillating. However, as the regeneration control is further advanced the selectivity again decreases. The difference between Curves 3 and 4 of Fig. 5, which were both taken with the same setting of the regeneration control but for different signal levels, shows that the effective selectivity of a regenerative circuit is dependent upon the signal level. This might be expected when one considers that the tube parameters (plate impedance, mutual conductance, etc.) are dependent upon the grid swing when the tube is not operating on a linear portion of the characteristic.

REGENERATION AND AMPLIFICATION

The relatively high amplification obtained when operating a regenerative receiver near the point of critical regeneration is widely known. The relation of Fig. 3 for a signal frequency corresponding to that of resonance of the tuned circuit, shows that since the effective resistance approaches zero as the point of critical regeneration is approached, the tuned circuit impedance becomes increasingly greater. In the case of capacitive coupling employed as in Fig. 1, and in general where a tuned circuit is used for the grid circuit of a regenerative detector, it can be shown by circuit analysis that the resultant amplification is a direct function of the tuned circuit impedance (Z_o).

The experimental curves of Fig. 6 show the relative variation of the regenerative amplification (ratio of E_b to E_a, Fig. 1) as the regeneration control is varied. In plotting these curves, the screen grid voltage being the regeneration control, the screen voltage as a percentage of its value at critical regeneration was taken for the abscissa. Curves 1 and 2 for the regenerative amplification of a modulated signal show little difference, though Curve 1 was obtained with the screen-grid tickler arrangement of Fig. 2B while Curve 2 results with the more usual plate-tickler arrangement of Fig. 1. Curve 3 was obtained for c.w. reception with a non-oscillating regenerative detector and separate heterodyne (discussed later); while Curve 4 shows the change in amplification for c.w. reception with the regeneration control at values increasingly greater than the critical point. It will be noted in all cases that the

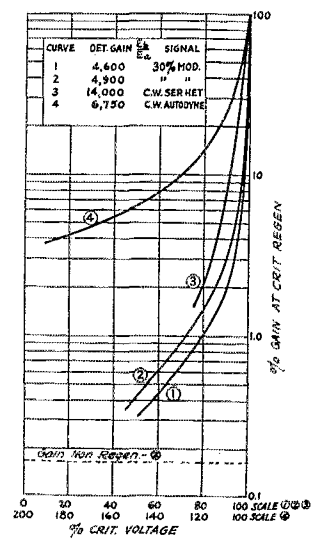

FIG. 6 — REGENERATIVE DETECTOR AMPLIFICATION. RESONANT FREQUENCY 7200 KC.

regenerative amplification falls off very rapidly for slight variations of the regeneration control voltage.

The question of the limit to which the regenerative amplification can be carried and the effects of the tuned circuit, tickler, grid leak and tube characteristics are of interest. Considered from the standpoint of the reception of a modulated signal (detector non oscillating) the regenerative amplification is limited by the stability of the higher *L-C* ratio. Tuned circuit B was purposely made rather poor. The optimum screen-grid voltage for the Type '36 tube as a non-regenerative grid leak detector, for the plate load resistance and supply voltage employed in these tests, was approximately 30 volts at low signal levels.

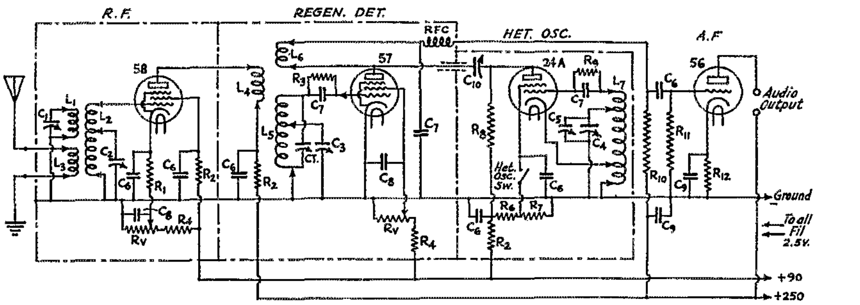

FIG. 7 — TYPICAL REGENERATIVE RECEIVER WITH SEPARATE HETERODYNE OSCILLATOR

Circuit values for the r.f. and regenerative detector stages and for the audio amplifier would be as usual. The oscillator circuit constants are as follows:

C_4 — *Same as C_2 and C_3, and ganged with them.*
C_5 — *Oscillator vernier trimmer, 25 μμfd.*
C_6 — *.01 μfd.*
C_7 — *100 μμfd.*
C_{10} — *Insulated wires overlapped 2 inches or so.*
L_7 — *Same as L_4 and L_5 but tapped for cathode about ⅓ turns from grounded end.*
R_2 — *5000 ohms.*
R_6 — *25,000 ohms.*
R_7 — *50,000 ohms.*
R_8 — *50,000 ohms.*
R_9 — *100,000 ohms.*

circuit elements, tube characteristics and supply voltages which determine the maximum value of regeneration obtainable without self-oscillation. This limitation is particularly serious in the case of regenerative receivers operating from the a.c. power supply which is usually subject to rapid voltage fluctuations of several percent. With this limitation, the regenerative amplification was found to be nearly directly proportional to the non-regenerative detector gain. In other words, the values of tuned circuit, grid leak, screen grid and plate voltages which give the maximum detector gain in the non-regenerative condition, also result in the maximum regenerative detector gain (non-oscillating) for the same output signal level.

This is substantiated by the experimental data of Table I. The automobile tubes Type '36 and '37 were employed and are representative of results obtainable with other types. The data on the tuned circuits referred to in this table are given in Table II. Tuned circuits A and C are both fairly low-loss circuits, circuit A having a considerably

The data of Table I show that by adjusting the tickler coupling so that the point of critical regeneration occurs at this optimum screen voltage, maximum amplification was obtained as a regenerative detector. The value of the grid leak seemed to be of minor importance and values from one to five megohms showed little difference. Increasing the signal level on the detector (here measured in turns of the output level E_o) results in a decided decrease in regenerative gain. The regenerative amplification was greatest for the lower-loss tuned circuits and increased with the *L-C* ratio. The screen-grid tickler arrangement of Fig. 2B resulted in practically the same regenerative amplification at critical regeneration as the more usual plate-tickler circuits. The triode Type '37 tube as the regenerative detector (in circuit Fig. 2A) gave only slightly over one-third the gain of the screen-grid tubes.

Considered from the standpoint of the reception of c.w. signals (oscillating detector), the regenerative amplification is also a maximum at the point of critical regeneration and hence is

TABLE II—TUNED CIRCUIT DATA

7200 kc.

Tuned Circuit	*L/C Ratio* $\times 10^4$	C_1 *μμfd.*	L_1 *μh.*	*Coils — Tube Base; En. Wire Close Wound*			
				L_1 *Turns*	*Wire*	L_2 *Turns*	*Wire*
A	39.7	35	13.9	16¼	No. 20	7	No. 30
B	6.01	90	5.42	8	30	7	30
C	5.52	94	5.19	9	20	5	30

limited by any instability of circuit elements or supply voltage fluctuation which will not permit operation very near this point. A fairly high value of grid leak (3 to 5 megohms) decreases the amplitude of the self-sustained oscillations and results in a detector action over a restricted region of the tube characteristics. Hence the conditions for maximum detector gain for an oscillating detector approach those for a non-oscillating

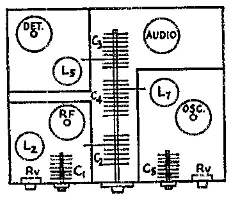

FIG. 8 — SUGGESTED LAYOUT FOR A REGENERATIVE RECEIVER WITH SEPARATE HETERODYNE OSCILLATOR

regenerative detector. The data of Table I confirm this, the detector gain for c.w. reception increasing as the point of critical regeneration is shifted to the optimum value by adjusting the tickler coupling. The effect of the tuned circuit impedance and other factors seem to be much less pronounced than in the case of the non-oscillating detector. The screen-grid tickler circuit of Fig. 2B again shows the same amplification as the plate tickler arrangement.

SUMMARY

Tuned circuit *L-C* ratios and losses are of minor importance in regard to selectivity in a regenerative circuit.

Lower loss tuned circuits and higher *L-C* ratios result in increased regenerative amplification.

Regenerative amplification and selectivity decrease very greatly for slight departures from point of critical regeneration.

Regenerative detector amplifications as high as 7000 for 30% modulated reception and 15,000 for c.w. reception are obtained at critical regeneration and optimum adjustments.

Critical adjustment and improved stability of circuit and voltages are of major importance.

Optimum regenerative detector voltages and circuit constants are practically the same as for maximum non-regenerative detector gain at the same signal output level.[2]

A REGENERATIVE RECEIVER WITH SEPARATE HETERODYNE OSCILLATOR

After having considered the relative advantages and disadvantages of regenerative circuits and detectors, as amateur operators our chief interest lies in their application. There follow a few brief remarks and suggestions concerning an unusual adaptation of the regenerative circuit to amateur receiver design. No attempt is made to give the detailed construction since every amateur will desire to suit his fancy in that respect. The receiver has been constructed and is rendering excellent service in active amateur work.

At first glance the amateur might question, "Why should one complicate a perfectly good regenerative receiver by adding a separate heterodyne oscillator?" In truth, it is necessary to hear a receiver of this type in operation and actually handle it in service to appreciate fully the improvement in stability, sensitivity and ease of operation. The suggested schematic diagram is shown in Fig. 7, although the circuit can be modified readily to suit particular needs. Fig. 8 is a typical layout arrangement. The receiver consists essentially of a more or less standard tuned r.f. amplifier and regenerative detector with the usual audio amplifier stages. The separate heterodyne electron-coupled oscillator may be either separately tuned or ganged with the main tuning control. In either case the small oscillator trimmer capacitor, variable from the front panel, is essential as a frequency vernier. The heterodyne oscillator must be very carefully shielded,[3] since only a very low level (less than 500 microvolts) is coupled to the detector grid. A switch is provided in the screen grid circuit to cut the oscillator off when not in use. Other methods of coupling the oscillator to the detector may be employed and the optimum coupling is not critical or difficult to determine in the initial adjustment of the receiver.

For c.w. reception the receiver is tuned in the usual manner as a regenerative receiver, with the regeneration control slightly advanced beyond critical regeneration causing the detector to oscillate and having the separate heterodyne oscillator switched off. When a desired signal is heard the regeneration is decreased just enough to cause the detector to stop oscillation, the separate heterodyne oscillator is switched on and tuned with the small variable capacitor. The result is an unbelievably stable signal, increased sensitivity and freedom from the a.c. hum modulation so common to a straight regenerative a.c. receiver.

As the data of Table I and curves of Fig. 6 have shown, the sensitivity with the separate heterodyne oscillator is somewhat better than for the straight regenerative detector alone. Instead of a very feeble oscillator (as in the case of an oscillating regenerative detector at critical regeneration) subject to very considerable variations of frequency and amplitude with power supply fluctuations, with the separate heterodyne oscillator one has a very stable, vigorous oscil-

(Continued on page 90)

[2] For detector data on Type '27 and '24 tubes, see Robinson, "Vacuum Tube Detectors," *QST*, August and September, 1930.

[3] Lamb, "Single-Signal Superhet," *QST*, August and September, 1932.

ruled against "prehistoric" signals, "ac" and unduly broad notes, so we hope there will be "none such." "1933-type" stations with *good* notes and stable frequencies should make *your* work in this contest more successful and enjoyable. A.R.R.L. Official Observers are requested to put in all time possible notifying amateur stations observed off-frequency or with improper-type signals, operating during the contest period . . . and Observers' reports for this period should be sent in through S.C.M.s at the conclusion of the contest.

Results in previous Relay Competitions indicate that the majority of stations worked were raised, not by sending CQ, or testing on a half-dozen frequencies — but by *first* listening and locating foreign amateur stations, then going after them. No excuse for ten minute CQ's. The stations in remote localities, *not* W/VE stations, are the ones using CQ most effectively in previous international-DX affairs. The planning of best use of frequencies and operating hours for most effective participation and *real operating skill* are necessary to successful DX-work.

Regenerative Detectors

(*Continued from page 30*)

lator. The regeneration control can be maintained right at the critical point with the resultant high amplification, since there is little danger of the detector breaking into oscillation with the supply fluctuations. If this occurs it cannot be noticed (unless the regeneration control is very greatly advanced) since the separate heterodyne oscillator holds the detector oscillations in synchronism. The heterodyne oscillator can be calibrated, if carefully constructed, and employed as a frequency meter as well.[4]

It is hoped that this information may prove helpful to amateur experimenters and further stimulate amateur receiver development.

An Amplifier for the Beginners' Crystal Transmitter

(*Continued from page 22*)

A FINAL HINT

The output of the amplifier depends a good deal upon the size of the grid leak resistor, R_7. The higher the resistance, the lower the output. Maximum output will be secured with no resistance at all in the circuit, the key being connected directly between the end of the grid choke and the filament center-tap or minus "B" lead. It is better to have about 1000 ohms in the circuit, however, especially when the preliminary adjustments are being made, since the bias developed by grid current flowing through the resistor will hold down the plate current to the amplifier tubes. After the set is lined up, however, R_7 may be shorted out.

The power supply described in the November issue will give approximately the voltages indicated in Fig. 2 when handling the complete transmitter. If a different power supply is used it should be kept in mind that these voltages should not be exceeded if the tubes are to behave properly and have reasonably long life.

[4] "Electron-Coupled Oscillators as Frequency Meters," *QST*, July, 1932.