The Modern Armstrong Regenerative Receiver

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Lee de Forest's invention of the Audion in 1906 led to marvelous developments in radio receiver technology. But it was not until Major Edwin H. Armstrong conducted a thorough investigation of the principles of operation of the new three-electrode tube that the technological jump took place. Mr. Armstrong applied in 1913 for a patent on the regenerative receiver, one of the most famous radio inventions, maintaining a long litigation in the courts with the inventor of the Audion. However, he managed to develop a large number of radio circuits utilizing the principle of regenerative amplification or equivalently, positive feedback in amplification circuits.

The pioneering work of Major Armstrong on the regenerative receiver has come to our days in the form of the so called Armstrong circuit, the most popular receiver used by experimenters and Hams throughout the world. Its most basic representation is depicted in Fig.1 below.

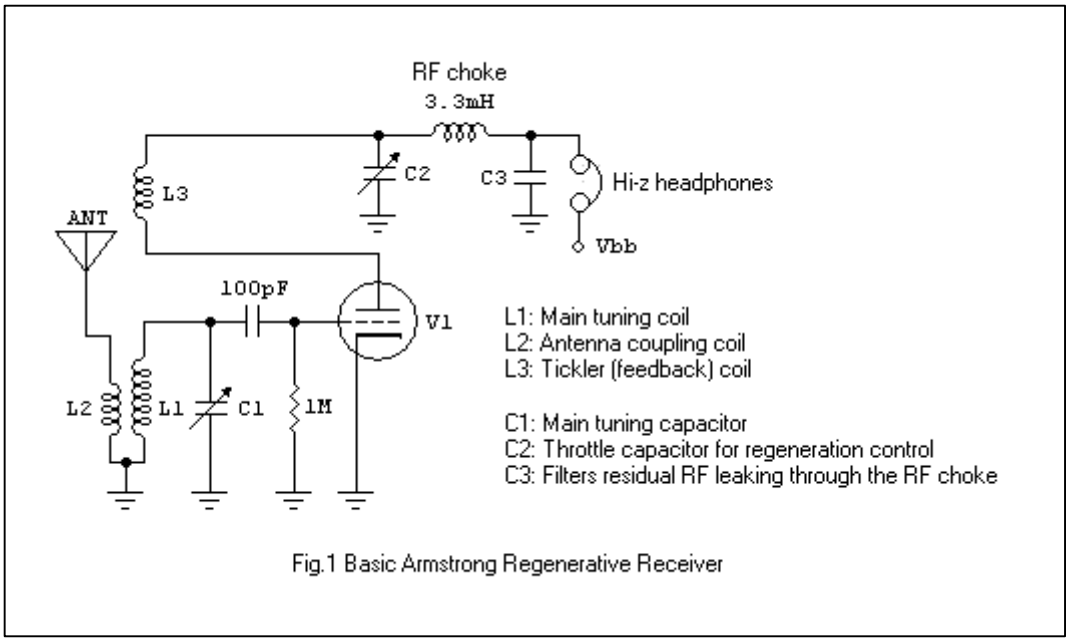

Fig.1 Basic Armstrong Regenerative Receiver

With reference to this circuit, the passing radio waves induce a voltage on the antenna. Induced currents flow through L_2, which magnetically couples the RF energy to the L_1-C_1 tuned circuit. The grid circuit elements, Cg =100pF and Rg = 1M couple the tuned radio signal to the triode's input. Amplified RF currents flow in the plate circuit, setting up a magnetic field around L_3 which couples energy back into the tank circuit in phase with that imposed by the radio wave, reinforcing it. Now we get stronger RF currents across L_3, more energy fed back in phase, again an amplification……

If enough energy is fed back and enough amplification is obtained from the triode, the circuit will break into oscillation. For DSBC (double side band with carrier) AM demodulation, we don´t want the receiver oscillating. The mission of the throttle

capacitor C_2 is to limit the amount of current flowing through L_3 so that the circuit won´t oscillate. C_2 is adjusted so we get maximum amplification of the incoming radio signal. Usually, this occurs when the circuit is in the threshold of oscillation.

Regenerative receivers need rather small operating-point currents, and it is not unusual for them to operate satisfactorily with low plate voltages. Low currents also make regeneration control smoother.

AM demodulation is accomplished through grid-leak detection. Fig.2 shows the key to understanding this type of detection. First, the triode's input is modelled as a diode pointing downwards. When the grid turns positive with respect to the tube's cathode, due to the presence of the positive half cycle of the carrier, some electrons emitted by the cathode are attracted by the grid, flowing in the external circuit to the grid capacitor. As a result, the grid capacitor replenishes its charge. During the carrier's negative half cycle, conduction between cathode and grid stops and charge leaks from the capacitor through the external circuit (L_1 and the grid resistor). The next incoming carrier cycle the phenomenon repeats itself. The combination of Cg = 100pF, Rg = 1M and the equivalent diode act as a voltage-clamp circuit.

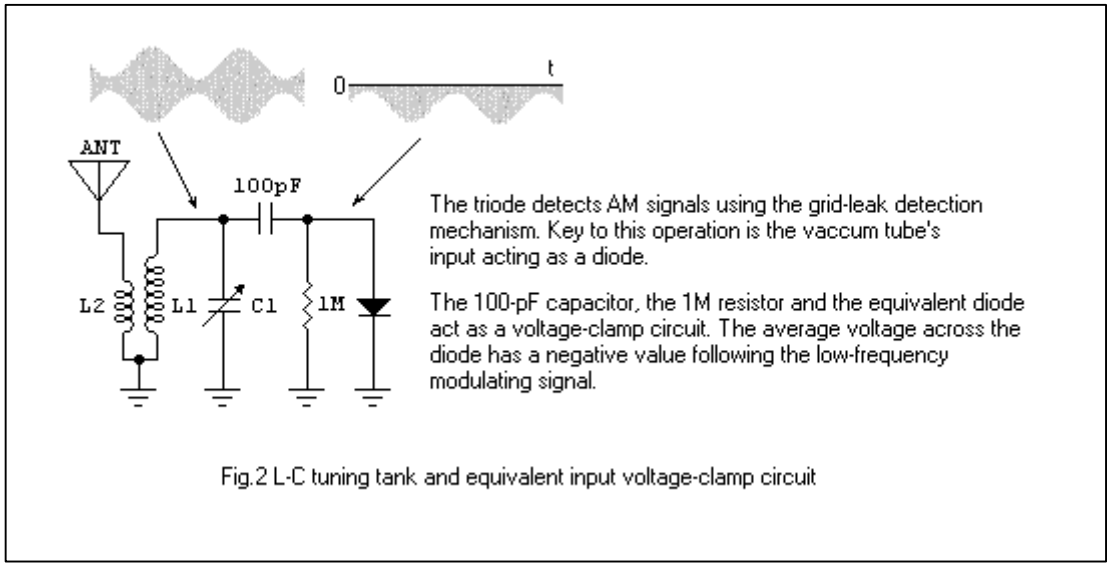

Fig.2 L-C tuning tank and equivalent input voltage-clamp circuit

The final result is that a negative average voltage equal to the carrier's amplitude develops across the triode's input. If the carrier is amplitude modulated, the average voltage follows the modulating signal. What is interesting here to note is that in the absence of a carrier the control grid-to-cathode voltage is almost zero. After carrier detection, the average voltage turns negative, so there will be a drop in the average plate current. If the carrier is amplitude modulated, the average plate current will decrease in more or less degree, following the modulation.

It should be clear that an amplified version of the modulating signal exists at the tube's output in the form of low-frequency variations of the plate current. An RF choke prevents the high-frequency components of this current from circulating through the high-impedance headphones, which are acting as an audio load (Fig.1).

However, RF-choking action is not always 100% efficient, and some RF energy may leak into the headphones or following AF stages. This could give rise to some very

strange effects, such as low-frequency motorboating at some value of the throttle capacitor, or the receiver breaking into oscillation when the throttle capacitor's vanes are fully unmeshed. Usually, selecting an RF choke with enough inductance will keep these problems away. A decoupling capacitor may also help. In Fig.1, capacitor C_3 by-passes any residual RF components, leaving only AF currents flowing through the headphones. For grid-leak detection to work properly, the grid-circuit time constant:

$$t = Rg \times Cg = 1M \times 100pF = 0.0001 \text{ sec} = 1E\text{-}04 \text{ sec} = 100 \text{ µsec}$$

should be much greater than the carrier's period T. For example, for the MW AM broadcast band, the lowest tuned frequency is 530kHz. For this case, T = 1.887E-06 sec, or 1.887 µsec. Clearly, $t >> T$. However, t can not be made to be too large, or failure-to-follow distortion will occur in the recovered audio. If T_A is the period of the highest modulation frequency, then the inequality $T_A > t$ should be accomplished. Let 3kHz be the maximum modulation frequency component. Then, T_A = 3.33E-04 sec = 333 µsec, which is greater than t = 100 µsec. Thus, the selected values for Rg and Cg are correct. Due to an important property of the voltage-clamp circuit, the tuning tank sees a parallel load approximately equal to Rg/3, or 333.33k ohms in our case.

The solid-state Armstrong regenerative receiver

The Armstrong circuit has also its solid-state counterpart, and historically speaking, it has been devised using bipolar transistors as well as junction FETs (JFETs) and insulated-gate FETs (IGFETs or MOSFETs).

There is an important difference in the detection action of the solid state version. We shall base our comments on the Armstrong receiver shown in Fig.3 that will tune the 530kHz~1700kHz MW AM broadcast band.

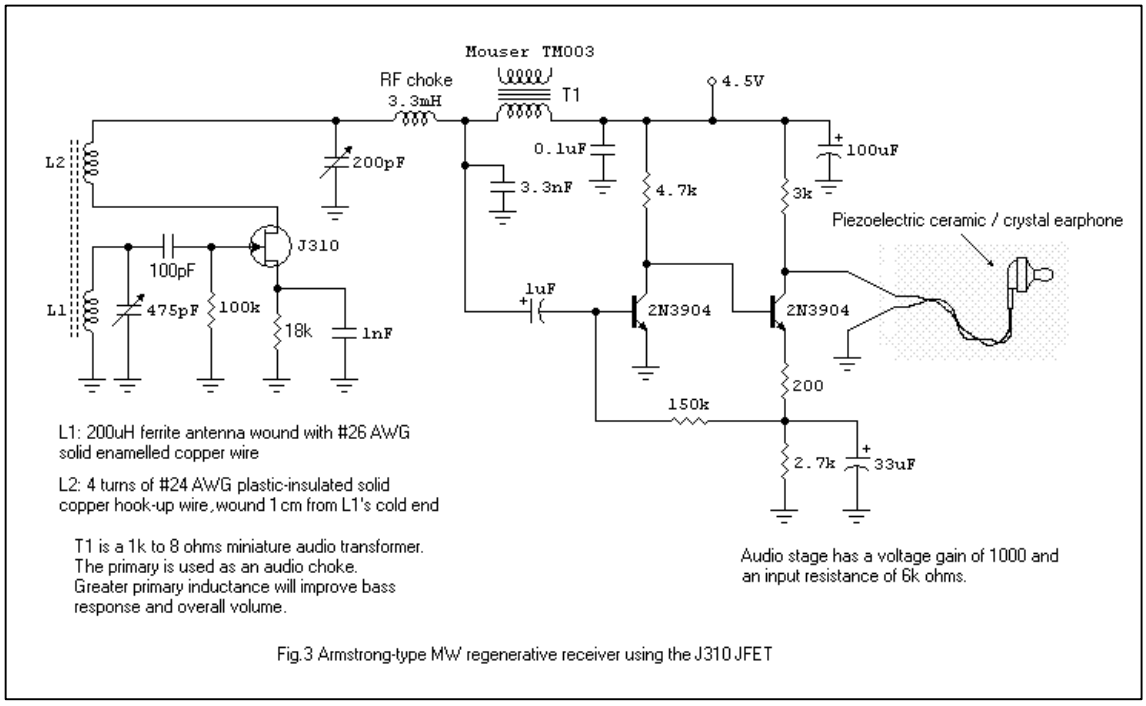

Fig.3 Armstrong-type MW regenerative receiver using the J310 JFET

A vacuum tube is a robust electron device. It may stand reasonable signal overloading and some abuse also. Solid-state devices are delicate and need protection circuitry. The J310 JFET of Fig.3 is not an exception. We need to include a source resistor for protection and biasing reasons. Without this resistor the quiescent current would be too large, some 30mA according to the manufacturer. Really too big for our purposes. The gate-source junction would be also vulnerable to very strong signals that eventually could reach our receiver.

In the figure above, the 18-kohm source resistor regulates the drain current I_D to 0.157mA when the power supply is 4.5 Volts DC. So we get 2.83 Volts for the voltage drop across the resistor. The gate-source bias-voltage is then -2.83 Volts. For a 9-Volt supply, the JFET's drain current increases only to 0.16mA. We get a very steady operating-point current with respect to power supply variations. The resistor needs RF decoupling and that is the reason for the 1nF capacitor. It is recommended a Mylar type. Greater capacitance values are not recommended, as they can make the circuit operate as a relaxation oscillator for high regeneration levels. This is an unwanted feature.

This said, "grid-leak"- type of detection is virtually cancelled. A VERY strong signal would be needed to overcome the gate-source bias and make the corresponding junction to conduct. Detection now is of the square-law type. The non-linear characteristics of the JFET make this possible. The "grid" R-C components have no effect on the detection action and have been maintained there for nostalgic reasons only. The receiver seems to be a bit more selective if these components are left in the circuit, although no explanation has been found for this.

The modulation is extracted from the junction of the RF choke and the primary winding of the Mouser TM003 audio transformer acting as an audio choke. The 3.3-nF capacitor, also a Mylar type, filters any residual RF component leaking through the 3.3-mH RF choke and that may be entering into the AF amplifier.

The two-transistor amplifier has a voltage gain of approximately 1000 and has an input resistance of 6k ohms at 1kHz. A piezoelectric ceramic / crystal earphone gives comfortable listening.

One final comment is that a ground plane underneath the circuit's layout is needed for stable and hand capacitance-free operation. Connect the circuit's common ground to this plane.

References

1. Edwin H. Armstrong's "Wireless Receiving System", US Patent 1,113,149
2. http://hjem.get2net.dk/helthansen/regenerative_vacuum_valve.htm

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