From ***Feed Line*** No. 5

REGENERATION REVISITED
The Tesla Connection
by Gary L. Peterson

Pick up nearly any book on the principles of radio, turn to the chapter on receivers and you will see it—the primary objectives to be achieved in detector design are sensitivity, selectivity and stability. Historically, some of the very first detectors consisted simply of a tuned circuit into which was incorporated a sensitive device known as a coherer. With the introduction of two and three element vacuum-tube circuits as a replacement for the earlier coherer based designs further important steps were taken towards the advanced receivers of today. One of the first improvements in the triode, or Audion, based circuit was dubbed the Regenerative Detector. In this configuration, conceived of by Edwin H. Armstrong in 1912, a portion of the signal from the plate circuit was coupled as positive feedback to the tuned antenna tank circuit. The result was greatly increased receiver sensitivity.

Focusing on receiver sensitivity or the ability to pick up weak signals, it is important to understand the antenna design concept of "effective area." This refers to the fact that a tuned antenna may have an effective area that is larger than its geometric area. The phenomenon was first explained by Reinhold Rudenberg in 1908 [1] and the description has been expanded upon over the years by many other writers. In the words of Dr. John F. Sutton from his recent active antenna patent, "Rudenberg teaches that the antenna interacts with the incoming field, which may be approximately a plane wave, causing a current to flow in the antenna by induction. The [antenna] current, in turn, produces a field in the vicinity of the antenna, which field, in turn, interacts with the incoming field in such a way that the incoming field lines are bent. The field lines are bent in such a way that the energy is caused to flow from a relatively large portion of the incoming wave front, having the effect of absorbing energy from the wave front into the antenna from a wave front which is much larger than the geometrical area of the antenna." One of the factors that limits antenna current is the ohmic resistance of the tuned detector tank circuit and the antenna wire itself. Regeneration is a means of increasing antenna current by counteracting the resistance of the entire antenna circuit. By the introduction of what might be called negative resistance through the addition of a feedback loop, antenna-field interaction is increased and energy is absorbed from a greater area of the incoming wave front.

How does Nikola Tesla fit into this picture? In a New York American article of Sept. 3, 1911 while speaking of his receiver design he said that it "concentrates the energy transmitted over a wide area into the device." This statement was made about one year prior to Armstrong's discovery related to RF feedback to the grid-antenna circuit. In fact, we can see that Tesla recognized the utility of the feedback technique to introduce negative resistance into antenna circuitry and had incorporated it in his designs as early as 1899. On August 3 of that year he recorded a number of receiver circuit arrangements in which RF currents were fed back from the secondary side of a resonant transformer to a coherer located on the transformer's primary side. In this form of receiver, which Tesla had described as using a "self-exciting process," the coherer was made significantly more sensitive to incoming signals. In his own words, "This method has been found excellent and will have besides telegraphy many valuable uses since by its means effects, too feeble to be recorded in other ways, may be rendered sufficiently strong to cause the operation of any suitable device." So it may be said that Tesla anticipated the technique of regenerative feedback to increase detector sensitivity.

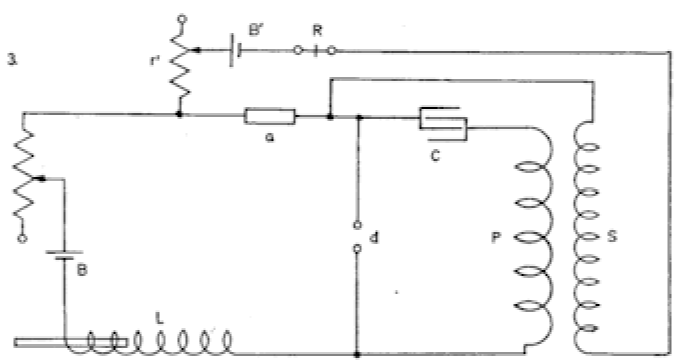

Figure 1. "In Diagram 3. the form of connections is illustrated which was found most convenient for experimentation. An independent sensitive relay is used and adjustable dead resistances r and r' in primary and secondary circuits. The inductance L is also made adjustable and so is also break device d though this is not indicated in the diagram."

The basic regenerative circuit is not often used in present day receiver front ends for a number of reasons, the most significant of these being an inherent form of instability. Maximum sensitivity is achieved at a point just before the detector breaks into oscillation and in the original configuration this could be initiated by something as simple as wind shifting the antenna. As the appearance of oscillating regenerative front ends on the broadcast bands became a more and more regular occurrence a decision was made to phase the regenerative detector out of general service. A related difficulty is the need to reset the degree of regeneration as the detector is tuned. In spite of these problems the increases in sensitivity to be gained through the incorporation of this powerful technique have not been totally lost on the minds of the engineering community. Goaded on by this understanding, a few years ago Dr. Sutton set out to develop a positive feedback antenna circuit configuration that would be very sensitive to low level fields while at the same time being resistant to the influence of stray capacitive and inductive reactances. Figure 1 is a schematic diagram of a circuit that was developed which satisfies these requirements.

Typical values for the components shown are: R1=10k, R2=100k, R3=10 S, R4, R5, R6, R7=10k, R8=30k, and C1=1000 :fd. Amplifiers A1, A2 and A3 may be Precision Monolithics OP-27s. Electrostatic shielding is provided to reduce capacitive coupling between the two windings.

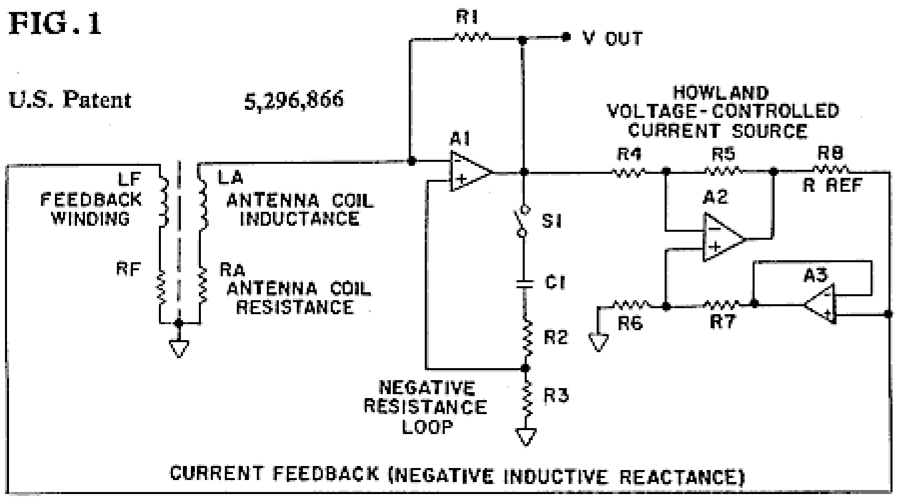

Figure 1. U.S. Patent No. 5,296,866

As the specific design problem was development of an optimized broadband ELF magnetic field sensor, an active antenna with a wide frequency response was also a criterion. This posed a design challenge as in a typical tuned antenna circuit significant antenna current, and thus maximum sensitivity, is only present with conditions of resonance. Under normal circumstances, peak resonance occurs at some very specific frequency where inductive reactance is canceled out by capacitive reactance. The innovative solution was to add a second feedback loop to the circuit which introduces negative inductive reactance that works in place of circuit capacitance to tune out inductive reactance. This results in an antenna circuit with a resonance that, under ideal conditions, would have an infinite bandwidth.

All in all, the same conditions which exist in a passive narrow band tuned antenna, vis-á-vis resonance, antenna current and effective area, are electronically created in the antenna coil. Furthermore, the active resonant antenna has a bandwidth which is in the order of four decades wider. The net result is a unique active antenna circuit that can be reliably adjusted in which total antenna circuit impedance is much smaller than appears to have been obtained with any other configuration to date.

A detailed description of how the negative resistance, negative inductance circuit works, including a differential form of the active antenna circuit and other pertinent information, can be found in U.S. Patent No. 5,296,866, Mar. 22, 1994, Active Antenna, GSC-13449. For data look at "An Active Antenna for ELF Magnetic Fields," J.F. Sutton and C. Spaniol, Proceedings of the 1990 International Tesla Symposium; and "Atmospheric Fields, Tesla's Receivers and Regenerative Detectors," K.L. Corum, J.F. Corum, Ph.D. and A.H. Aidinejad, Ph.D. Another useful reference is the Colorado Springs Notes -- 1899-1900, by Nikola Tesla.

[1] Rudenberg, Reinhold, "Der Empfang Elektrischer Wellen in der Drahtlosen Telegraphie" ("The Receipt of Electric Waves in the Wireless Telegraphy") Annalen der Physik IV, 25, 1908, p. 446-466.

See also Causality, EM Induction and Gravitation, Oleg Jefimenko)