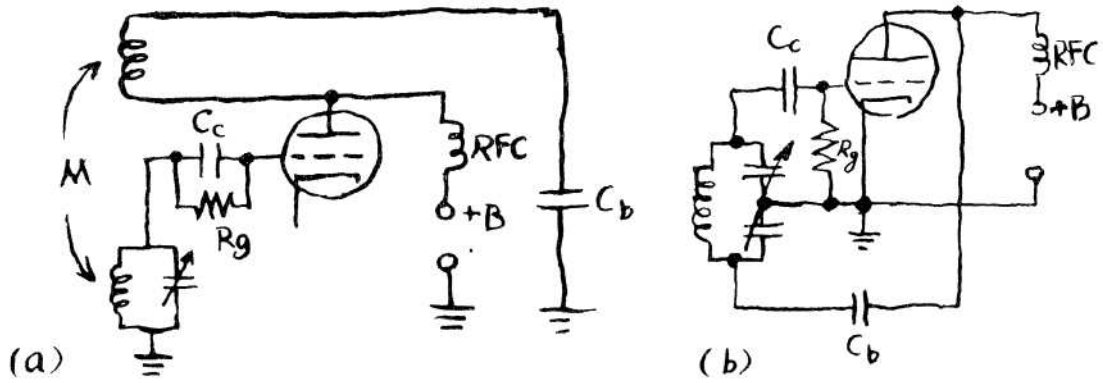
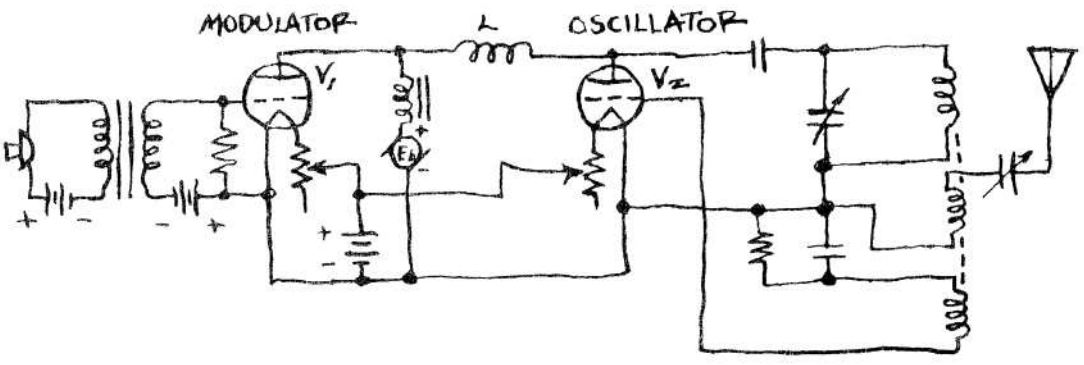
1. VACUUM-TUBE OSCILLATOR: c. 1912

The vacuum-tube oscillator generated continuous waves at a single frequency, unlike its predecessor, the spark gap, thus permitting communication over a single channel. Using positive feedback and the triode as an energy pump, it provided a sine-wave output at the resonant frequency of its tuned circuit. Several individuals invented the circuit in about 1912 independently, notably Reginald A. Fessenden, Alexander Meissner, H. J. Round, and Lee de Forest, but the arrangements by Edwin H. Armstrong (a) and Edwin Colpitts (b)—a similar circuit was devised by R. V. L. Hartley—were used most widely in the early going.



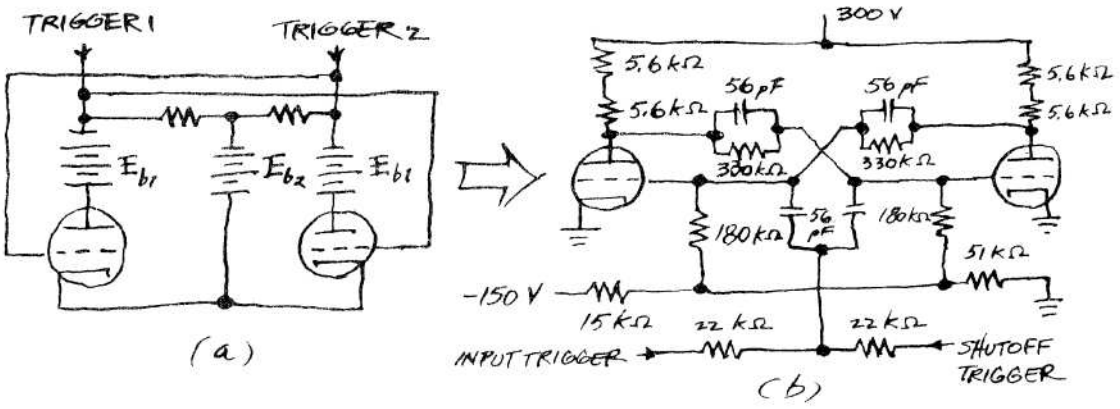
2. CONSTANT-CURRENT MODULATOR: 1913

R. A. Heising's vacuum-tube circuit, initially conceived at Western Electric in 1913, was the first modulator capable of working efficiently. With inductor L preventing any change in the total plate current drawn by V_1 and V_2, the modulating signal was applied to the plate circuit of the rf oscillator so that audio-frequency variations at the modulator's output would produce similar variations in the oscillator's plate current.



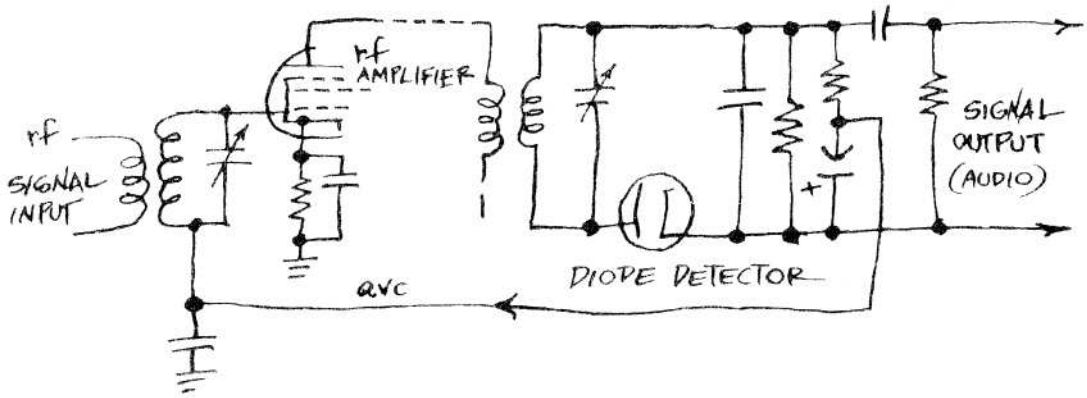
3. FLIP-FLOP: 1919

Among the many circuits derived from the general trigger arrangement (a) invented by W. H. Eccles and F. W. Jordan, working in the UK, were the monostable and astable multivibrators and the Schmitt trigger. The bistable latch, or flip-flop (b), is the ancestor of the frequency counter-divider and the computer.



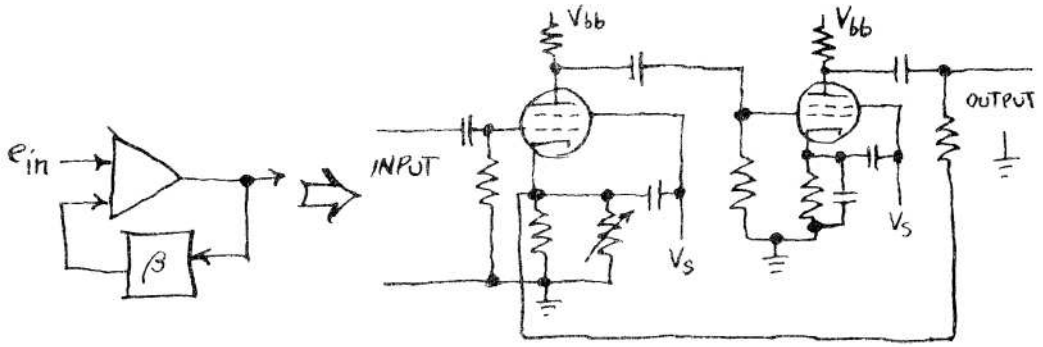
4. AUTOMATIC VOLUME CONTROL: 1926

One of the first circuits to utilize the properties of negative feedback, Harold A. Wheeler's automatic gain control for a-m radios provided a substantially constant audio output volume over a wide range of rf signal levels. Wheeler designed the AGC in 1926 at Hazeltine Corp., where he works to this day.



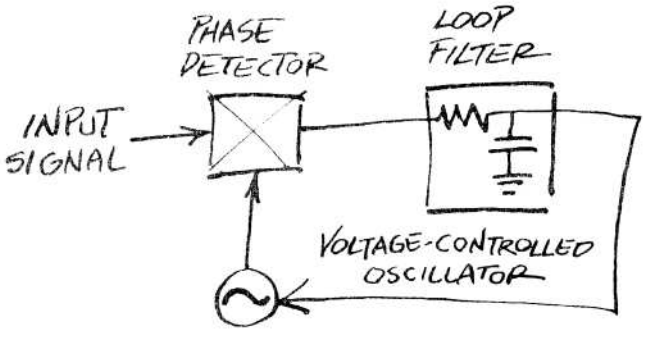
6. NEGATIVE-FEEDBACK AMPLIFIER: 1927

In one of the most fundamental developments in the history of communications, H. S. Black discovered that negative feedback could be applied to an amplifier to minimize distortion over a wide band of frequencies and achieve gain stabilization at the same time. This work, performed at Bell Telephone Laboratories in 1927, was different from that of Wheeler, who had earlier used negative feedback for control.



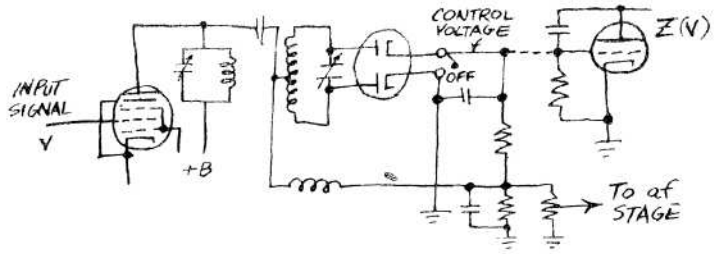
7. PHASE-LOCKED LOOP: 1932

H. de Bellescize, working in France, was the first to describe a system for the synchronous reception of radio signals, one that was simpler and more elegant than the superheterodyne approach then used. Using a feedback control loop to adjust a voltage-controlled oscillator to the exact frequency of an incoming signal, the PLL, originated in 1932, is employed widely in many data-processing and communications circuits today.



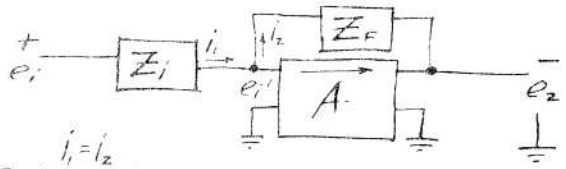
8. AUTOMATIC FREQUENCY CONTROL: 1935

Charles Travis's discriminator and reactance-tube circuit (shown here in a modified simplified version by S. W. Seeley), developed in 1935 while he was at RCA, formed the heart of the first automatic frequency control and was the basis of the reactance-tube modulator and the Foster-Seeley discriminator for fm detection.



10. OPERATIONAL AMPLIFIER: 1938

The discovery by G. A. Philbrick in 1938 of the operational amplifier for performing integration and differentiation by electronic means was not so much the invention of a circuit as it was the development of a concept. Using an odd number of ordinary high-gain vacuum-tube stages for generating the required 180° phase shift between input and output, Philbrick (also, independently, C. A. Lovell) showed that the transfer function of the network could be set with two external elements. This work led to the development of the active filter.



$$i_1 = i_2$$

$$\frac{e_i - e_i'}{Z_1(p)} = \frac{e_i' + e_2}{Z_F(p)}$$

$$e_2 = A e_i = \frac{Z_F(p)}{Z_1(p)} \left[\frac{1}{1 + \frac{1}{A}\left(1 + \frac{Z_F(p)}{Z_1(p)}\right)} \right] e_i \simeq \frac{Z_F(p)}{Z_1(p)} e_i \,, \quad A \gg \frac{Z_F(p)}{Z_1(p)}$$