The Invention of a Classic Circuit:

Automatic Volume Control

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"Blasting and Fading," again "Blasting and Fading," these words were heard over and over again by radio engineers in the later 1920s. All of the early 1920s work to improve amplification brought these engineers a new problem. Frustrated radio owners had to keep their hand on the volume control to manually regulate the increased sound capability designed into their new radios. The search was on for a solution to this problem.

The Invention of a Classic Circuit

As broadcasting began in the early 1920s, radio manufacturers had to design radios that could produce enough audio signal so that family and friends could all listen to one of the new horn speakers. Since the gain from the Radiotron triodes that were on the market was so low, the engineers claimed there was no need for a volume control. The popular tuned radio frequency (TRF) radios on the market required long antennas to bring as strong a signal as possible into two RF amplifiers which then fed into a detector tube and two audio amplifiers. If the listener lived close to a transmitter that made a station come in too loud, the listener could either slightly detune one of the RF stage dials or lower the filament voltage to the amplifier tubes.[1]

By the mid-1920s the demand for factory-built sets exceeded the demand for home-made sets, and radio engineers were hard at work to increase the performance of radios and their components. The problems they encountered came from all of the parts of a radio:

- The performance of triode vacuum tubes
- The quality and efficiency of horn and cone speakers
- The design of cascaded-tuned radio frequency amplifiers
- The capability to match different antennas
- The replacement of battery power with AC power
- The need for user-friendly radios

The radio broadcasters were creating improved programming to draw more listeners. The radio manufacturers saw the demand from the growing population of radio fans—fans who were ready to buy an improved radio. The time came for radio engineers, young and old, to get to work and it did not take long for each of the deficiencies to be addressed.

Harold Arlen Wheeler, Young Radio Inventor

At a time when many young men pursued an interest in wireless, one of these young men pursued wireless with more drive and skill than others. That young man was Harold Arlen Wheeler, born in 1903 to a family that would soon move to Washington, DC, as his father followed a career in the U.S. Department of Agriculture. As he built his wireless gear, others noticed that young Wheeler wanted to fully understand why things worked and what he could do to improve them (see Fig. 1).

William A. Wheeler arranged for his son to have a summer job at the National Bureau of Standards where he conducted performance tests on radio receivers. The receiver that most impressed young Wheeler was the Navy model SE-1420, and he soon learned that it was designed by Professor Louis Alan Hazeltine of the Stevens Institute of Technology in Hoboken, NJ.[2] In 1922, Secretary of Commerce Herbert Hoover convened the first National Radio Conference to gather information on this new technology to help the federal government form standards and regulations.

William Wheeler represented the Department of Agriculture at the conference, and Professor Hazeltine was also in that group. Wheeler took his son, then a student at Washington University, to meet the dignitaries at the conference, and it was there that the young Wheeler first met Professor Hazeltine.[3] Not long afterward, the Wheelers were passing through Hoboken, NJ, and had a chance meeting with Hazeltine in a restaurant. This resulted in a meeting in Hazeltine's office where the young Wheeler told Hazeltine of his own radio experiments, including his circuit to neutralize the

Fig. 1. Young Harold Wheeler working his ham radio. (*The Early Days of Wheeler and Hazeltine Corporation-Profiles in Radio and Electronics*)

effects of the capacitive coupling in the triode vacuum tubes then in use. Hazeltine revealed that a patent application for his invention of the Neutrodyne had already been filed. So, Hazeltine's invention of the Neutrodyne had not been put into a working model but a patent application had already been submitted, and Wheeler had a working model of his form of neutralization but he had not submitted a patent application.[4]

As Hazeltine's plans for the Neutrodyne took shape, he decided it would be better to come to a working agreement with Harold Wheeler and form some affiliation. Hazeltine arranged to visit the Wheelers to see Harold's work.[5] This led Hazeltine to make a generous offer to the inventive student. He offered a summer job to Wheeler for the period of his undergraduate and graduate studies, a full-time engineering position with the Hazeltine Corporation which was being formed, and 10% of the royalties Hazeltine would collect for the Neutrodyne, which would soon be coming to market.[6] This was a generous offer, considering that Hazeltine had no legal obligation to do so. Over the next several years, this generous offer would pay back many times over as Wheeler's patents and engineering skills became a major part of Hazeltine Corporation. This marked the beginning of what would become a life-long association.[7]

As Harold Wheeler returned to Washington to continue his education, Professor Hazeltine established the Hazeltine Corporation at Stevens Institute of Technology (see Fig. 2), and

Fig. 2. Navy building at Stevens Institute of Technology in 1923. The first offices of the Hazeltine Corporation and Harold Wheeler were on the top floor of the "temporary" building. (Author's Collection)

the Neutrodyne radios were being sold to many thousands of radio fans around the country. Radio engineers at Hazeltine Corporation, the Radio Corporation of America (RCA), and others were working on ways to improve radio receivers and their components. To satisfy radio fans who wanted to buy the next great thing in radio, the manufacturers looked ahead to see what was needed. More amplification, simpler antenna requirements, better sound quality, single or two-dial tuning, and radios that could run on the AC power that comes into the home were many of the challenges that lay ahead. When Harold Wheeler came to Hoboken to begin his summer job, he found that the Hazeltine engineers were confronting many problems to achieve these goals.

Big Advances in Radio: Vacuum Tubes

Three major advances took place in the manufacture of radio tubes. First was the creation of radio tubes with AC-powered filaments. In early vacuum tubes, the glowing filament was the source of electrons being drawn to the plate. For this reason, early radios could only run on batteries. In radios using the new AC vacuum tubes, the AC filament was surrounded by a cylindrical cathode. This AC-powered filament indirectly heated the cathode, which was then the source of the electrons. This advance and others saved the radio owner the work of frequently getting batteries charged or replaced, certainly a strong selling point for replacing the old radio.

The second advance was the introduction of what came to be called the screen grid tube. Work on the screen grid tube began in the mid-1920s when General Electric (GE) scientist, Dr. A. W. Hull, had a happy moment of serendipity. His research on one vacuum tube problem led to the solution of another problem. He had placed a metallic screen around the plate element to separate it electrically from the grid (see Fig. 3). He found that it solved the grid-to-plate capacitance problem that plagued the earlier triode tube.[8] The screen had a sufficient number of holes to allow current to pass through from the grid to the plate and yet reduced the grid-to-plate capacitance to 0.025 pf., a negligible amount (see Fig. 4). With no feedback or regeneration, these new tubes were able to supply a much higher voltage amplification factor of 300 over the older triodes (a gain over 30 in an RF amplifier).[9] The first screen grid tube to become available in late 1927 and early 1928 was a dry cell tube type UX-222. This was followed by an AC filament version model UY-224 in 1929. As can be seen in the graphic comparison (see Fig. 5), the gain per stage could increase from 10 to 34, giving tremendous total amplification over the receivers from just a year before.[10] Radios of 1928 that were advertised as having a receiving radius of 100 miles were being replaced with screen grid sets that had a receiving radius of 1,000 miles (see Fig. 6). This meant that shorter antennas could be used (see Fig. 7).

During the 1920s there were steady improvements in audio output tubes. The early 1920s receivers used the 01A as the RF and audio output amplifiers.

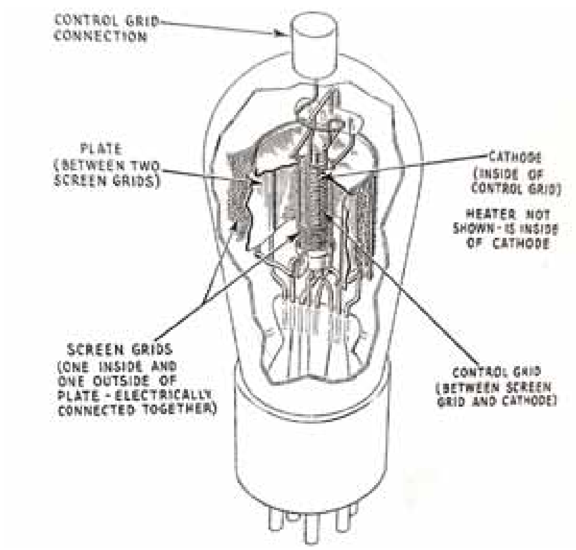

Fig. 3. Structure of the screen grid tube. (Eric Wenaas, *Radiola: The Golden Age of RCA, 1919–1929*, p. 336)

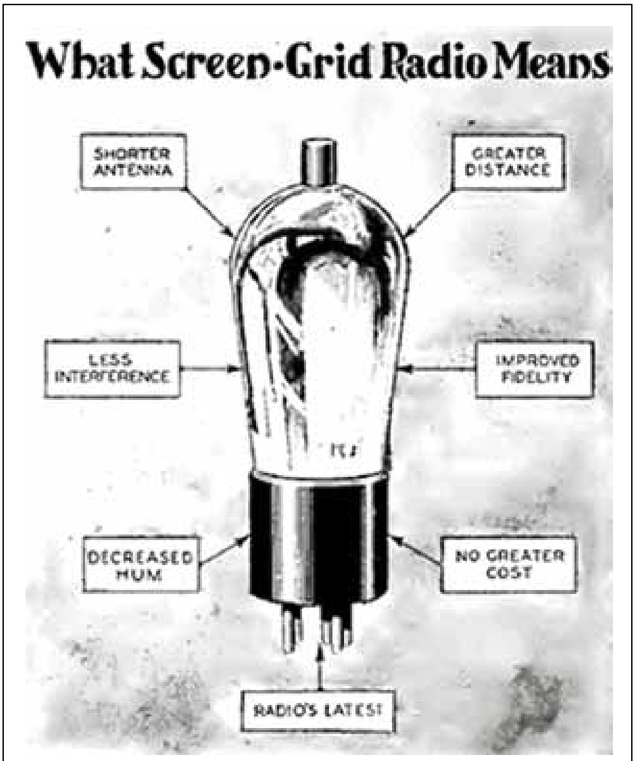

Fig. 4. What screen grid radio means. Benefits of the screen grid tube. (*Radio Broadcast*, Aug. 1929, p. 212)

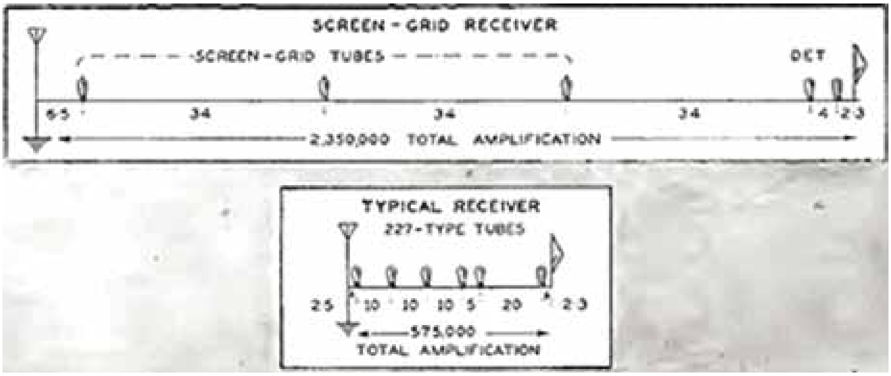

Fig. 5. A screen grid receiver using five tubes compared in overall amplification with a six-tube receiver using conventional tubes. (*Radio Broadcast*, Aug. 1929, p. 212)

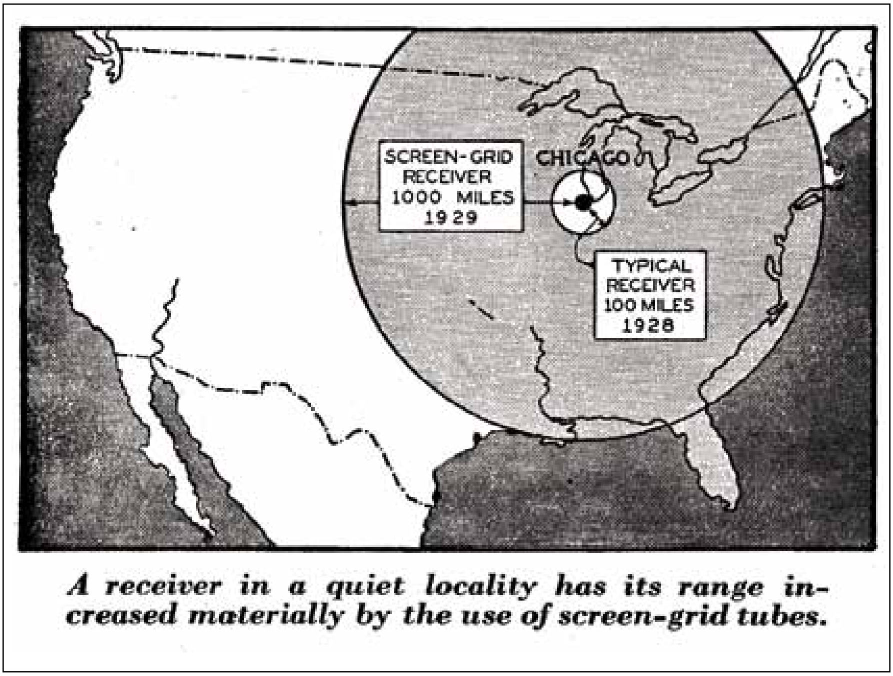

Fig. 6. The reception area with a screen grid receiver increases greatly in comparison with a similar triode radio model. (*Radio Broadcast*, Aug. 1929, p. 213)

As shown in Table 1, work progressed over the years and the power output steadily increased from a fraction of a watt to as much as 4.7 watts.[11] Soon, tubes with the ability to run on AC filaments with greater amplification and increased power outputs were offered in radios. To fully take advantage of this advance, a new speaker was needed to do the job.

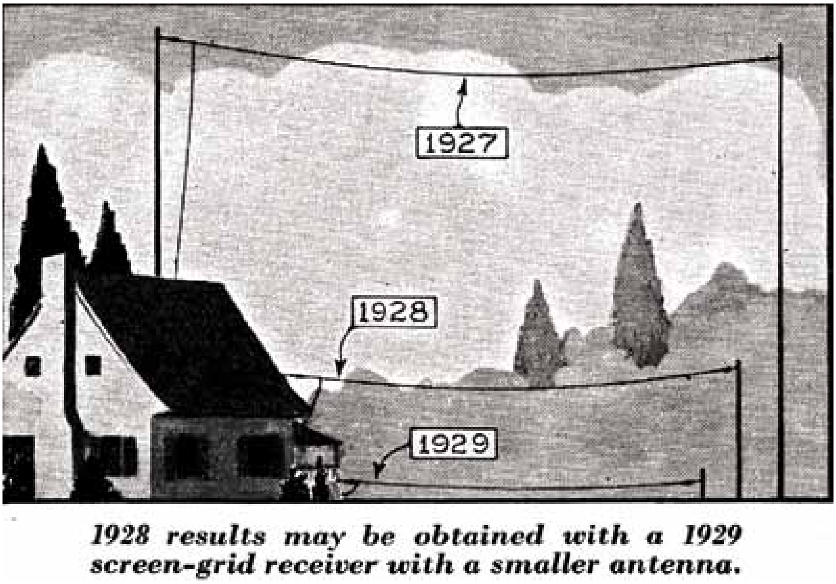

Fig. 7. More gain in the receiver gave the listener good reception with shorter antennas. (*Radio Broadcast*, Aug. 1929, p. 213)

Output Tube	Power, Watts	Year Introduced
01-A	0.05	1921
199	0.07	1924
120	0.11	1925
112	0.285	1925
71-A	0.79	1926
210	1.5	1925
45	2.0	1929
47	2.7	1929
50	4.6	1928

Table 1. Early vacuum tubes that used in audio output applications. (Advances in audio output tubes, *Saga Of The Vacuum Tube,* pp. 299–322)

The Electrodynamic Speaker

As broadcasting began, the device that converted the electrical signal into audio for the listener was the radio headset. This device, derived from the telephone earpiece, soon evolved into what became known as the horn speaker, which was able to produce enough audio for a group of listeners. The efficiency and fidelity of these speakers were poor because they had very little low-frequency response, resulting in a "tinny" sound. Speaker development shifted to what became called a cone speaker or magnetic speaker. Based on paper shaped like a cone, with a driver attached to the center, it gave some small improvement to the audio quality. These speakers were not part of the radio receiver but were purchased separately.

The research work of Chester W. Rice and Edward W. Kellogg at GE led to the development of a new type of speaker known as an electrodynamic speaker, a moving coil speaker, or simply a dynamic speaker.[12] The first commercial use of this technology was in the Radiola 104 loudspeaker (see Fig. 8). It included a 6-inch cone with a coil wound on a cylinder attached to the apex, which was placed in the air gap in the electro-magnet. The outer rim of the cone was attached to a flexible leather ring which was then mounted on a metal frame with an air gap ring. The cabinet of the Model 104 included a separate power supply to

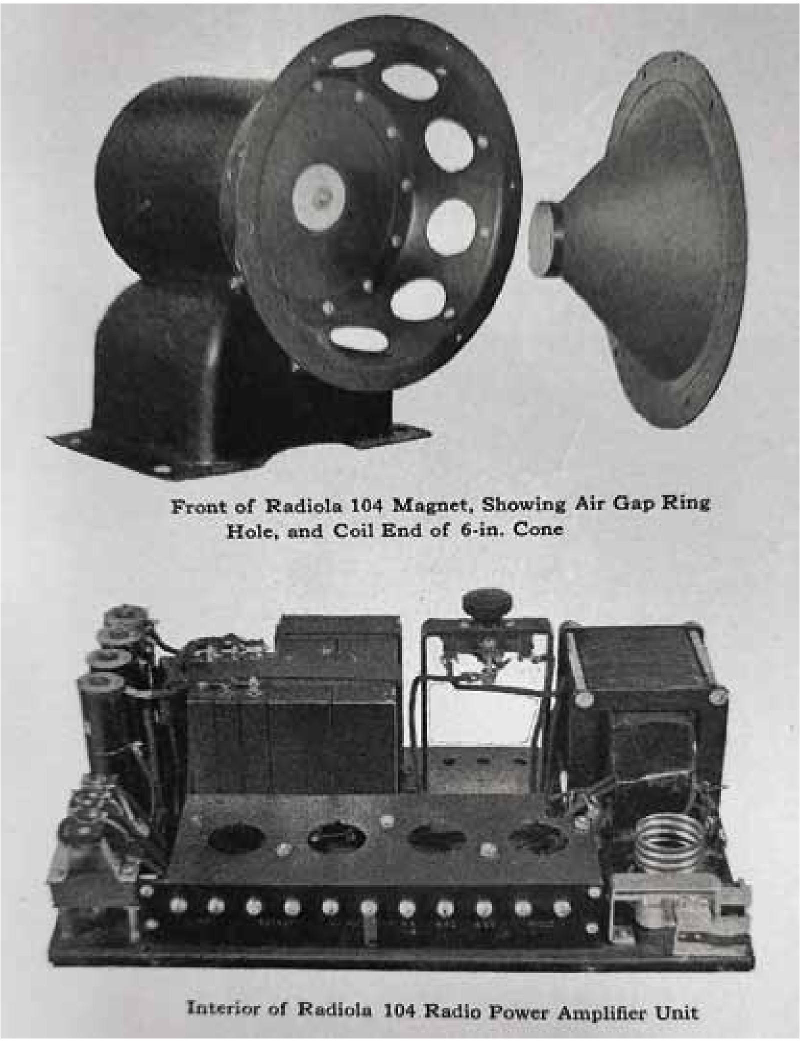

Fig. 8. Radiola 104 construction showing cone and magnet and the radio power unit. (General Electric *Review*, Vol. 30, No. 1, Jan. 1927, pp. 70, 71)

power the magnet and eliminated the A, B, and C batteries in the receiver.[13] The diagram of Fig. 9 shows the basic operation of the new speaker. The powerful magnet moves the voice coil to match the audio signal thus moving the attached cone which is supported by the outside ring. Three improvements made the new speakers simply louder and better:[14]

- Improved efficiency
- Improved fidelity
- Improved load-handling capacity

As a result, companies like Magnavox produced the new speakers for other radio manufacturers (see Fig. 10). As the new AC tubes found use in many new radios, they included a power supply

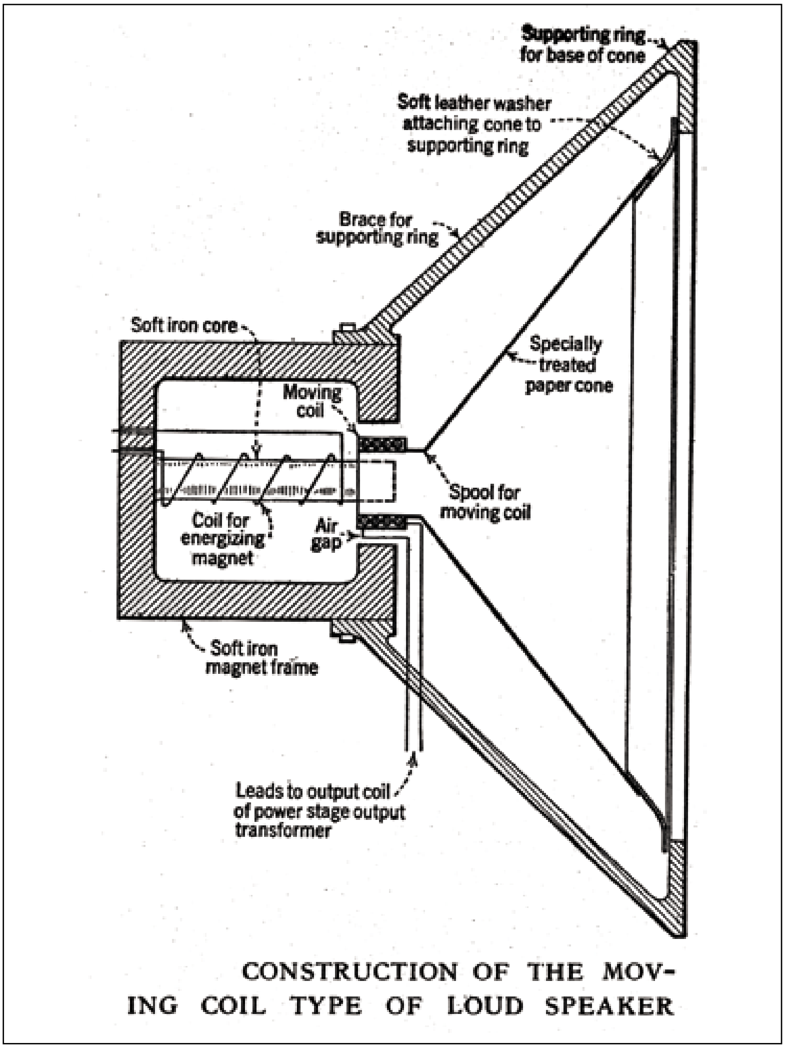

Fig. 9. Construction of the electrodynamic speaker. (*Radio Broad*cast, Dec. 1928, p. 110)

that could operate both the receiver and the speaker. Led by Majestic, the new loudspeakers used in the new receivers were built directly into the cabinet. It quickly made Majestic the sales leader of the radio market. The new speaker alone made their radios stand out from their competitors.[15]

Fig. 10. Magnavox and others began the production of electrodynamic speakers for sale to radio manufacturers for inclusion in their radio console receivers. (*Radio Broadcast*, Vol. 13, p. 60)

The TRF radios of the early 1920s required the operator to tune three dials to optimize the performance of each RF (radio frequency) amplifier tube. To simplify the operation, the tuning was soon reduced to two dials or even one dial. This was done by mechanically ganging three tuning condensers to be moved by one or two dials. This was a compromise because the RF stages did not electrically match each other to identically track with the single mechanical movement. It was made workable by having additional gain produced by more stages of amplification or by using the new screen grid tubes. This additional gain allowed receiving the stations that were somewhat tuning off track, but it had the adverse effect of causing blasting by stations that were tuning on track when the operator dialed across the broadcast band. Another fault with TRF receivers was caused by non-uniform gain across the broadcast band. From the low end of the band, the gain steadily increased as tuning was moved to the high end of the band. These conditions, along with the increased gain of the new vacuum tubes and the audio power of the electrodynamic speaker, caused performance that could vary from very low volume to very great volume.

New radio models produced with the new vacuum tubes and speakers that had tremendous amplification were being sold in radio stores. Some manufacturers of custom high-end radios, for fans that would only accept the latest and greatest, began production of radios with all of these improvements. Charles Leutz, always ahead of the pack, offered the Seven Seas model (see

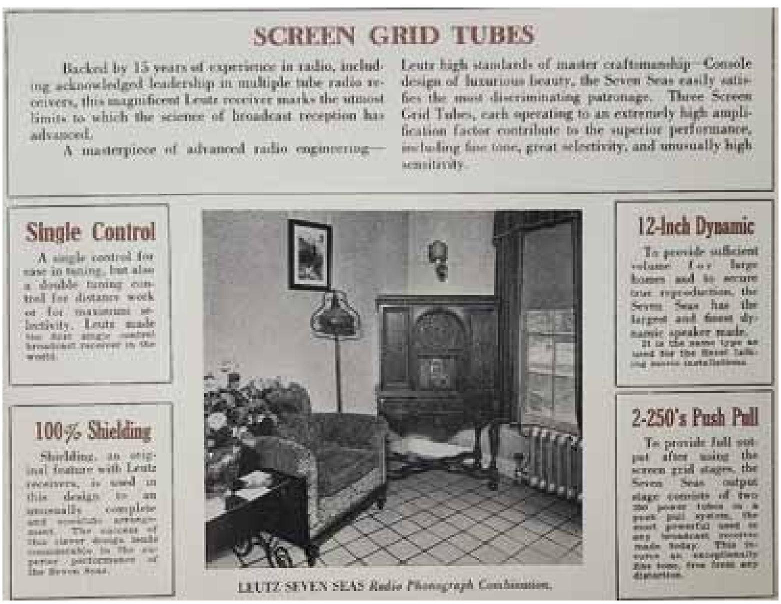

Fig. 11. Advertising sheet for Leutz Seven Seas console, an early screen grid receiver. (Author's Collection)

Fig. 11) with the new screen grid tubes. Their associated company, Norden-Hauck, took a different approach and offered some models with 10 triode tubes to reach high amplification (see Fig. 12). The Leutz Seven Seas model, which used three screen grid tubes and a push-pull audio amplifier fed into an electrodynamic speaker was offered all in a beautiful cabinet (see Fig. 13). With these new advances in radio equipment there now was an obvious need for a volume control. Engineers were confronted with a new problem and the problem was described as 'Blasting and Fading." When the Seven Seas model started blasting there was no mistaking it; the operator needed to stay near the volume control or suffer the consequences (see Fig. 14).

Fig. 12. Experimenters Information Services, Inc. ad showing amplification of 1,500,000. Before the screen grid tubes, this much amplification required ten triodes. (*Popular Radio*, May 1925, p. 55)

Fig. 13. Leutz Seven Seas console radio with all of the latest advances except AVC. (Author's image)

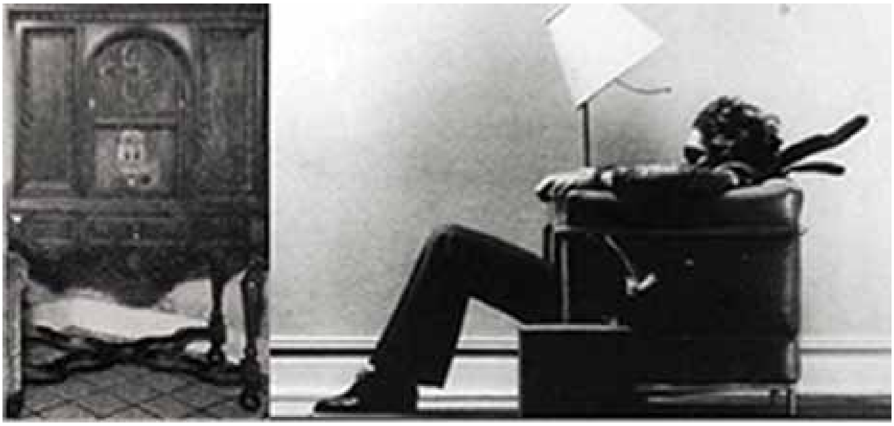

Fig. 14. Stay near the volume control of these radios or suffer the consequences! (Author's image)

The Invention of the Automatic Volume Control (AVC)

Harold Wheeler was one of many engineers who recognized the volume control problem and worked on a solution. It was his practice to keep notebooks of his work for reference at later dates and we are fortunate that from written interviews we can read Wheeler's personal account of the invention process:

> "In the summer of 1925, just after graduating from George Washington University in Washington, DC, I went to work a third summer in the Hazeltine Corporation laboratory. It was located in a few rooms in the attic of the Electrical Engineering building [Navy Building] of Stevens Institute of Technology in Hoboken, New Jersey, across the Hudson River from New York City. I was impressed with the amount of RF amplification in the latest designs of tunable receivers for radio broadcasting. Connected with an outdoor wire antenna, the sound level on local stations was so great that a "volume control" was needed to reduce the sound to a level suitable for listening. There were two tuning dials for the antenna circuit and RF amplifier so a "third hand" was needed for the volume control. I perceived that an automatic control was needed to set the sound volume at a desired level for all stations. Then the volume control knob could be set once for all stations within range. I soon decided that the automatic control should be applied to the RF amplifier ahead of the detector and AF amplifier. I aimed to do that by developing from the detector a bias voltage sufficient to control the gain in the RF amplifier if applied to the control grid of one or more of the RF amplifier tubes."[16]

The Construction of the Prototype: "The Washington Receiver"

> "In the fall of 1925, I entered graduate school at Johns Hopkins University in Baltimore, near my home in Washington. I planned to make a receiver with automatic volume control during the Christmas holidays in my basement laboratory at my home. I decided on a superheterodyne circuit to obtain sufficient RF amplification ahead of the detector. It was my first because that type of receiver was not in common use outside RCA (they refused to license its use by other companies). My design was an advance over others because I used a neutralized intermediate frequency (IF) amplifier at a frequency only slightly below the broadcast band (550–1600 MHz). This was a preview of later practice when the superheterodyne went into universal use a few years later, in 1930. I built this receiver on a work table. It was later preserved for exhibit in litigation so a photograph is available. It is now preserved in a showcase at the Hazeltine Corporation headquarters in Greenlawn on Long Island, New York [see Fig. 15]. It incorporated a modular design on eight small wooden bases [see Fig. 16]. I had accumulated the necessary parts before the holidays. There were tunable circuits for the antenna, local oscillator, and four IF circuits. The construction

of the receiver took only a few days and its operation was spectacular. Then I approached the problem of obtaining from the detector a bias voltage for automatically controlling the amplification in the first one or two of the IF stages. I had entered in my notebook some rather complicated circuits using

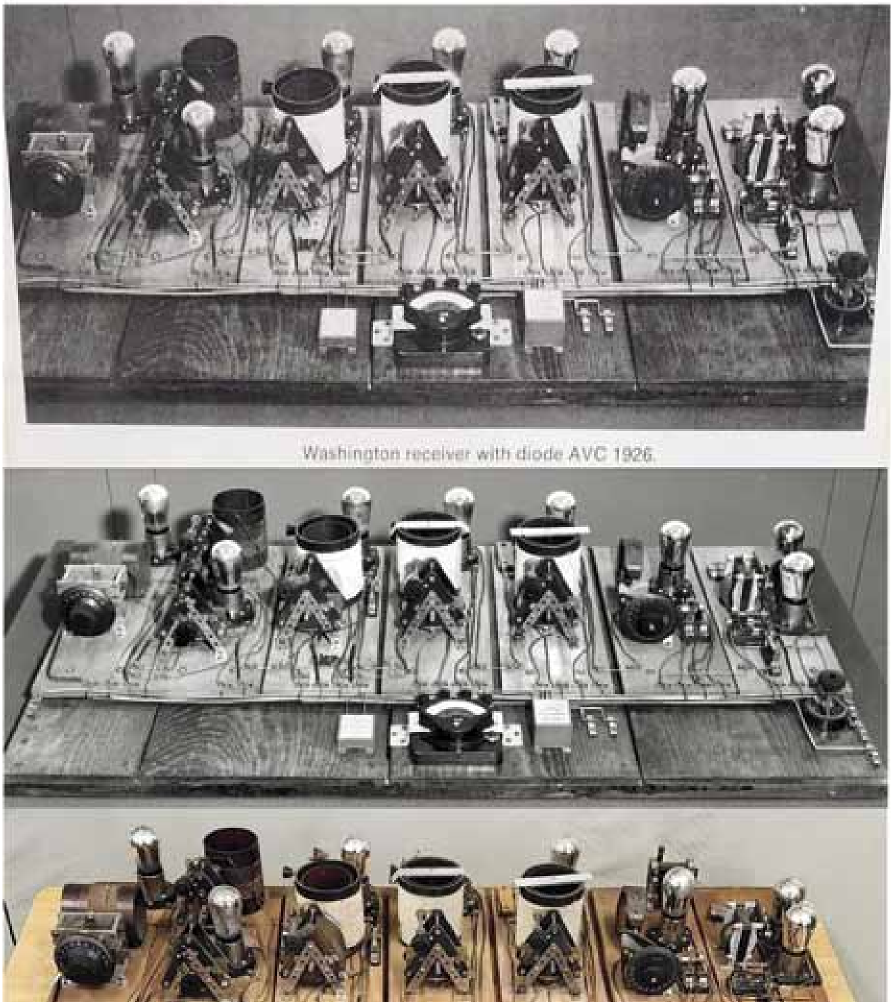

Fig. 15. Photos of the Washington Receiver. Top, an early picture; center, in Wheelers Office; bottom, as seen in the Radio Television Museum at InfoAge. (Radio Television Museum at InfoAge)

the usual triode detector. One problem I recall was the unavailability of resistors of values intermediate between wirewound (up to 1000 ohms) and graphite "grid leaks" (around 1 megohm). I needed some around 10 to 100 kilohms. Also, those circuits required a floating "B battery" in addition to the

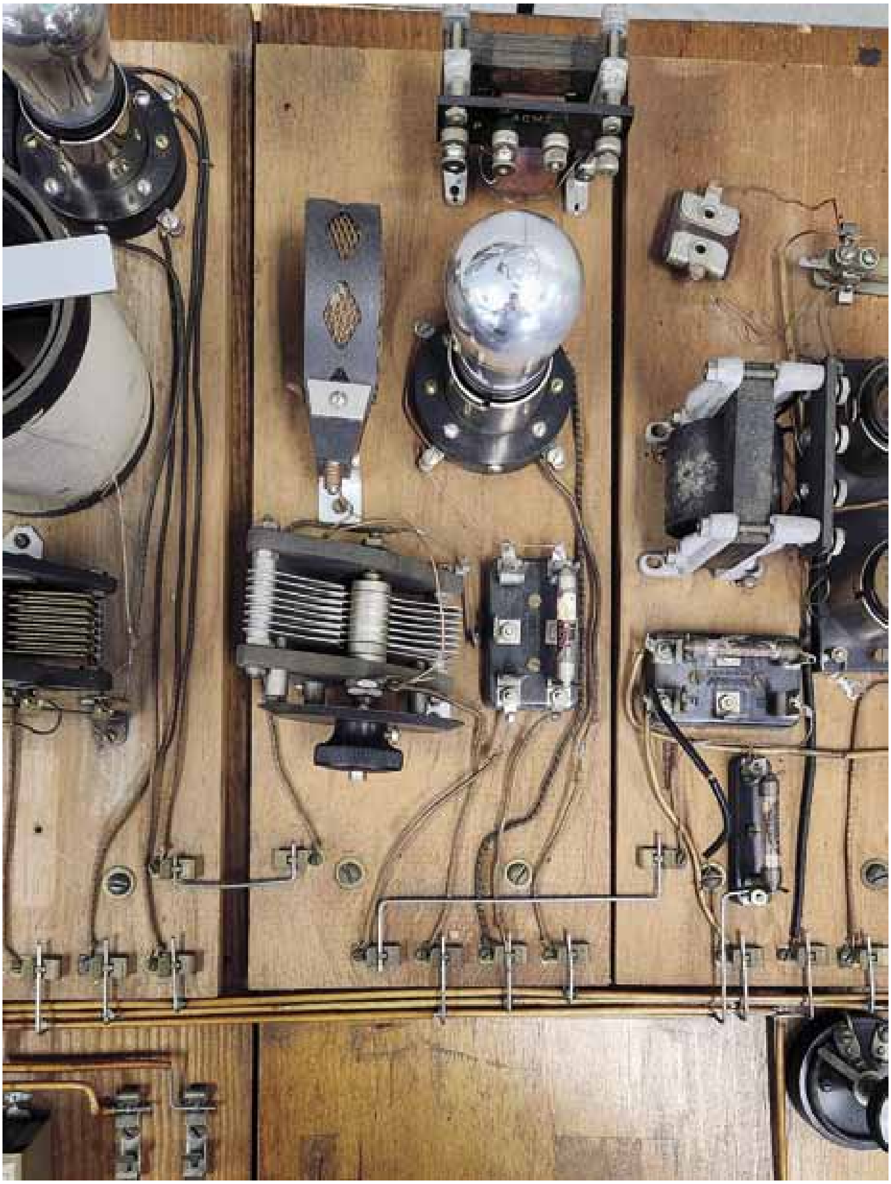

Fig. 16. The diode detector module of the Washington Receiver, as seen in the Radio Television Museum at InfoAge. (Author's Photo)

common grounded B battery for all amplifier stages. For a few days, I was making little progress. Then it occurred to me that I had enough amplification to use a diode rectifier as the detector, operating at 10 volts of IF signal. The diode would be made of the available triode with grid and plate connected together. This was heresy, to sacrifice the gain of one triode, costing about $5 apiece. However, the greater RF(IF) gain made up for the customary gain in a triode detector, so I still needed only two audio (AF) stages to drive the loud speaker. I quickly connected the diode with resistors and capacitors to provide separately the audio (AF) signal voltage and the bias (DC) voltage for control of the first one or two IF stages I got around to entering the theory of these connections in my notebook a few days later (January 2, 1926). This was the date we established later for "reduction to practice."[17]

How it Works

Several methods to automatically control the volume of a radio receiver were tried. RCA had an early AVC circuit in the Radiola 64. None of the early attempts proved to be satisfactory. In simple terms, a circuit had to use the level of the signal at the detector and use it to control the gain at the RF amplifiers. This is shown in the partial diagram in Wheeler's paper in the *Proceedings of the IRE* (see Fig. 17).[18] Wheeler's diode detector circuit, the triode wired as a diode, sent the audio signal to a triode for amplification and split off a second signal that consisted of the carrier wave, with the audio portion removed, and used it to develop a voltage sent to bias the grid of one or more RF amplifier to automatically adjust the gain to a level based on the level of the carrier wave coming out of the RF amplifiers. Wheeler stated that he arrived at this circuit after abandoning many complicated attempts and seeing

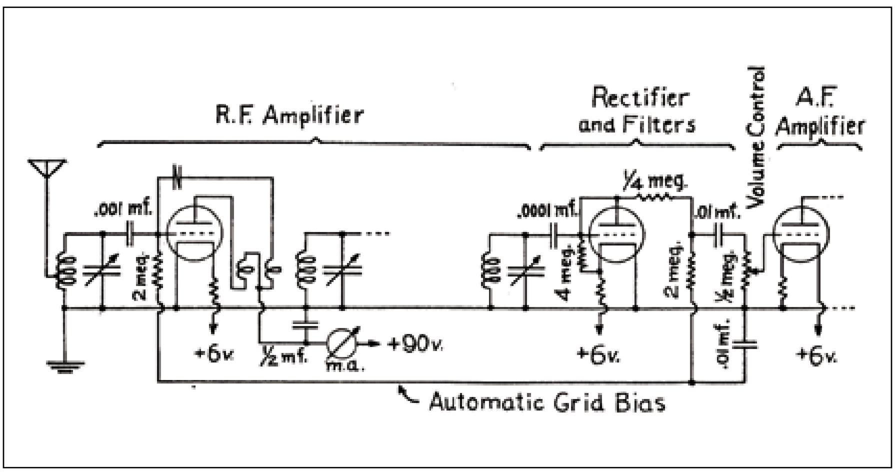

Fig. 17. Partial diagram of the AVC circuit showing the automatic grid bias path from the detector back to the RF amplifier. (*Proceedings of the Institute of Radio Engineers*, Vol. 16, No. 1, Jan. 1928, p. 31)

a simple solution. The performance was impressive and is shown in this graph as the detector gain levels off at the output (see Fig. 18).[19] The result is shown for controlling the gain of 1, 2, or 3 RF stages. This was the answer to the “Blasting and Fading” that plagued the new receivers using all of this newly acquired amplification to power up the improved speakers now available.

Patents

Since the early days of the Neutrodyne, Wheeler and the Hazeltine Corporation became familiar with the patent process and the effort required to defend the patents from infringers and legal challenges. As the patent applications for AVC were being prepared, it was understood that several applications would be filed to cover as many claims and survive as many challenges as possible. The first applications were filed on July 7, 1927, and more would follow.

As can be seen in Table 2, the process to have a patent issued was as long as 5–10 years.[20] The Hazeltine Corporation had to be confident in the protection of their applications and moved ahead by releasing an announcement of the AVC circuit and contacting their license holders to make plans to put the circuit into the top-of-the-line radios that would be manufactured. The value of the Neutrodyne patent dropped off as the need for the circuit had been superseded by the screen grid circuit. Now the AVC patent, combined with the engineering services of Hazeltine Corporation, gave value to the Hazeltine license. From 1932 through 1941, the diode AVC patents were the keystone of the Hazeltine license package. The royalties of their patents were the entire support of the Hazeltine Corporation laboratories, enabling them to continue a healthy level of activity through the depression of the 1930s.[21] Some major radio manufacturers used the AVC circuit without a license so Hazeltine Corporation filed lawsuits. The patent litigation came to a climax

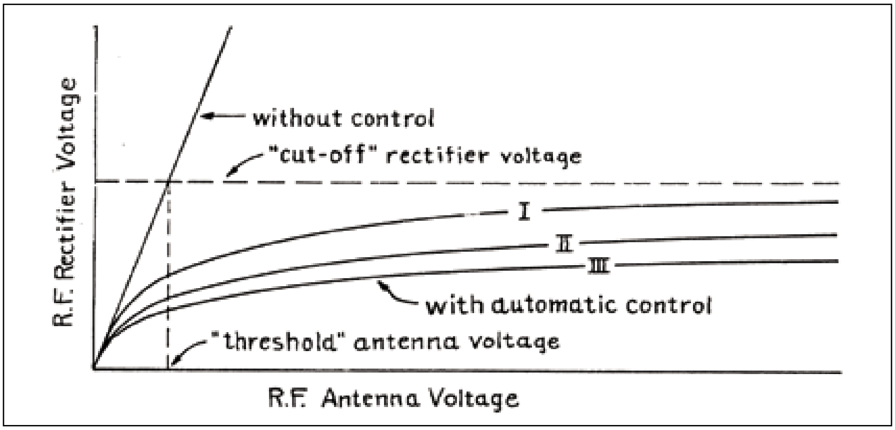

Fig. 18. A curve showing the action of the AVC circuit to lower the RF gain by adjusting one, two, or three stages of RF. (*Proceedings of the Institute of Radio Engineers*, Vol. 16, No. 1, Jan. 1928, p. 31)

Patent Number	Original Date Filed	Date Issued	Subject Listed
1879861	July 7, 1927	Sept. 9, 1932	Triode AVC
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1866687	Dec. 8, 1927	July 12, 1932	AVC by relay
2001950	Aug. 14, 1931	May 21, 1935	Triode AVC
2013121	Apr. 6, 1932	Sept. 3, 1935	Double AVC
Re 19744	July 7, 1927	Oct. 29, 1935	Diode AVC
2041273	July 7, 1927	Apr. 28, 1936	Linear AVC
2073038	Mar. 9, 1934	Mar. 9, 1937	Suspended diode AVC
2080646	July 7, 1927	May 18, 1937	AVC tuning indicator

Table 2. Wheeler patents related to AVC. (Author)

in a 1936 trial in Wilmington, Delaware, against RCA, which ended when RCA took out a license before a verdict was announced. Also, the AVC patent was validated in another suit against Detrola in Detroit.[22]

The Philadelphia Storage Battery Company (Philco), Hazeltine Corporation, and the Model 95

In the middle years of the 1920s, the Hazeltine Corporation and the Philadelphia Storage Battery Company were brought together by changes in the radio business that greatly affected the two companies. The early 1920s radios required A, B, and C batteries to operate, and the Philadelphia Storage Battery Company, which had been making batteries for automobiles since 1911, had been doing a growing business in radio batteries. Soon they developed a power pack that allowed the radio owner to draw power from the house current. However, this business did not last long as the radio manufacturers started producing radios that ran on AC, and their business plan was in trouble. In 1928 management decided to produce complete radios. Philco had earned a loyal network of dealers that sold their power packs and were anxious to sell the proposed Philco line of radio receivers.[23]

At the same time, the Hazeltine Corporation limited the number of licenses to the original members of the Independent Radio Manufacturers (IRM), but with the end of the Neutrodyne, Hazeltine Corporation was ready to add more licensees and provide them with more services, which could include a complete receiver design with the new AVC circuit. This situation was the exact relationship that Philco would need to get a quick start in radio manufacturing.[24] In addition, Philco purchased the Wm. J. Murdock Company, already associated with Hazeltine Corporation, and the Timmons Company, a well-established speaker manufacturer.[25]

In 1928 Philco, with the help of Hazeltine Corporation, came out with a full line of radios. The plan was to have a product of the highest quality at the lowest possible price to give the buyer the highest value. They were off to a good start, ending their first year coming in number 26 in the market. At the same time, the Grigsby-Grunow Company (Majestic) was going through the same transition as Philco. However, by increasing production and including the new electrodynamic speakers, Majestic became the industry sales leader in less than two years.[26] Philco was now ready to compete. The early 1929 product line used two different chassis: the Model 87 series chassis was the "Neutrodyne Plus" that used triodes and the Model 65 series that had the "Screen Grid" chassis, which utilized the new 224 Radiotron screen grid tubes. Both chassis could be matched to different cabinet choices.[27]

Under the direction of General Manager James M. Skinner, the management of Philco borrowed money to expand radio production. For 1929, Philco, relying on a strong network of dealers, planned to begin a national advertising campaign to promote a new line of top models using the new screen grid tubes as well as the new electrodynamic speakers. The Hazeltine Corporation was contracted to design the very top model. The project was assigned to Harold Wheeler, and it included the screen grid tubes as well as his diode AVC circuit.[28] The new receiver was designated Model 95, also advertised as the "Screen Grid Plus." Model 95 was first advertised later in 1929 in time for the Christmas season. It was offered with three different cabinet styles ranging in price between \$149 for the simple cabinet and \$220 for the deluxe cabinet.[29] This radio lived up to its advertisements. To the proud owner, the sound from the electrodynamic speaker came out loud and clear (see rear view of Fig. 20). The Philco ads stated that famous conductor, Leopold Stokowski, heard the Model 95, and for the first time permitted his famous Philadelphia Symphony Orchestra to perform on the radio (see Fig. 21).[30] The sensitivity of this circuit was such that it included a local-distant switch to prevent local stations from overloading the set and when the operator set the volume control to a comfortable level, the set could tune across the dial with a

Fig. 19. The 1929 Philco Model 95, Screen Grid Plus, in the Hi-Boy Deluxe cabinet. (https://www.tuberadioland.com/philco95_main.html)

Fig. 20. Rear view of the Model 95 with the Screen Grid Plus chassis. (Radio and Television Museum at InfoAge, author's photo)

Fig. 21. Philco advertisement announcing that famous conductor Leopold Stokowski will allow the Philadelphia Orchestra to perform on the radio thanks to the quality sound from the Model 95. (*Colliers* magazine, Sept. 14, 1929)

constant volume over an amazing signal variation of 10,000 to 1. A schematic is presented in Fig. 22 and the parts placement is shown in Fig. 23. Not only did the radio fans like the Model 95, but the radio reviewers in the radio publications were also impressed as in a report in the December 1929 *Radio Broadcast* magazine.[31]

In summary, the features of this receiver were:

1. A two-element detector tube that gave true linear detection and no

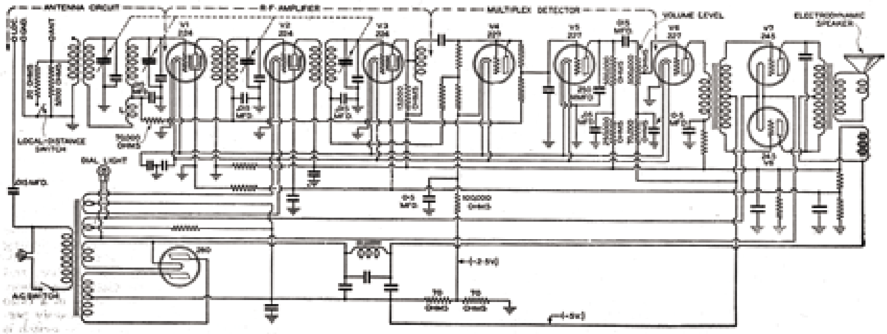

Fig. 22. Philco 95 schematic diagram Screen Grid Plus chassis. (*Radio Broadcast*, Dec. 1929, p. 112)

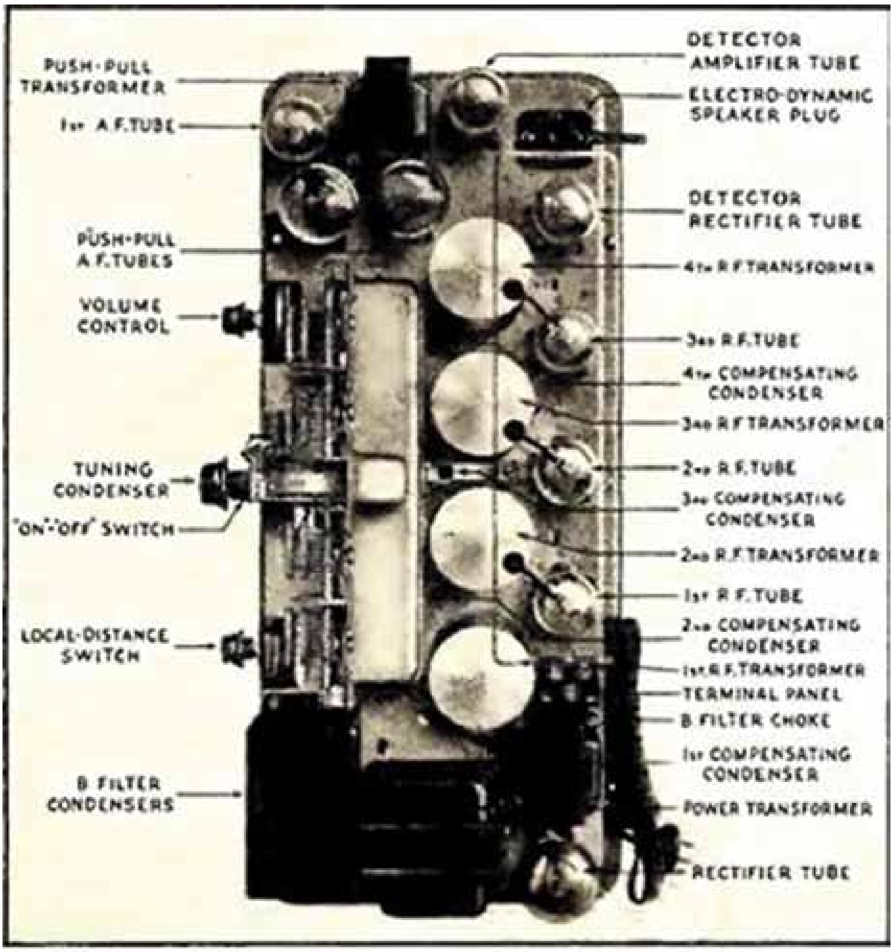

Fig. 23. Philco Screen Grid Plus chassis component layout. (*Radio Broadcast*, Dec. 1929, p. 111)

overloading on signals up to 100 volts input—an input greatly in excess of that possible.

2. Automatic control of volume and fading, that gave, in conjunction with the local-distance switch, satisfactory control of all field intensities in the ratio of 10,000 to 1.
3. A "multiplex detector circuit" was the name applied to the use of a twoelement detector in combination with an ordinary three-element tube working as an AF amplifier directly connected to the output of the two-element detector.
4. A local-distance switch that prevented overloading on strong local stations.
5. Uniform-gain antenna and interstage coupling circuits that maintained a constant sensitivity of about 5 microvolts throughout the broadcast band.
6. Simplicity of operation—the manual volume control seldom needed to be adjusted.
7. Excellent fidelity resulted due to the linear and non-overloading detector together with the resistance-coupled first AF stage and a push-pull power stage.

Skinner's plan to have Philco produce the best radios at the lowest possible price worked. In the 1929 year, Philco came in fourth in overall sales and Philco was able to repay its loans. As these models carried over into 1930, Philco became the sales leader of the radio industry. As the depression changed the radio market, Philco added low-cost models to its line and remained an industry leader for many years.[32]

This success also helped Hazeltine Corporation because others in the industry saw the need for incorporating AVC and other Hazeltine improvements into their products. The revenue that AVC license fees brought into the Hazeltine Corporation carried the company through the Great Depression,[33] and engineering work for the licensees kept the lab active throughout the 1930s. By 1932, AVC was a common feature in nearly all radios being produced. As the tag in Model 95 and others shows, the AVC patents had not yet been issued (see Fig. 24).

Fig. 24. The licensed RCA patents are listed on this Philco 95 tag but the AVC patents are still listed as other patents pending. (Author's collection)

Conclusion

In 1980, *Electronics* magazine took a look back in time for a historical appreciation of the electronic circuit inventions that had the most impact on the development of electronics to that point in the 20th century. They placed the AVC circuit at number four on their list.[34] Under the names of AVC, AGC (automatic gain control), and negative feedback, it was one of the most important and lasting circuit designs of the century. A sketch of the basic circuit is shown in Fig. 25. When adapted for television use, the AVC circuit was referred to as AGC. When television production began in the prewar era, there was no AGC circuit included. This meant that as the input signal varied the viewer had to adjust the contrast control as well as the vertical hold and horizontal hold. In postwar television production, AGC was included in the top model sets and soon in all televisions. Wheeler's circuit had found a new life.

As happens all too often, legal decisions regarding technical inventions are made by non-technical people, and as happened to Armstrong and his regenerative circuit, the United States Supreme Court made a legal decision about Wheeler's AVC invention. Companies that used the AVC circuit appealed through the court system to have the patent invalidated. In 1942 the court decided that AVC was not a new invention but rather a reconfiguration of existing technology. The patents regarding AVC were declared invalid but the technical community, such as those at *Electronics* magazine in 1980, recognized Wheeler's invention. By this time, the AVC royalties had seen Hazeltine Corporation through the depression, and Wheeler and the laboratory were busier than ever.

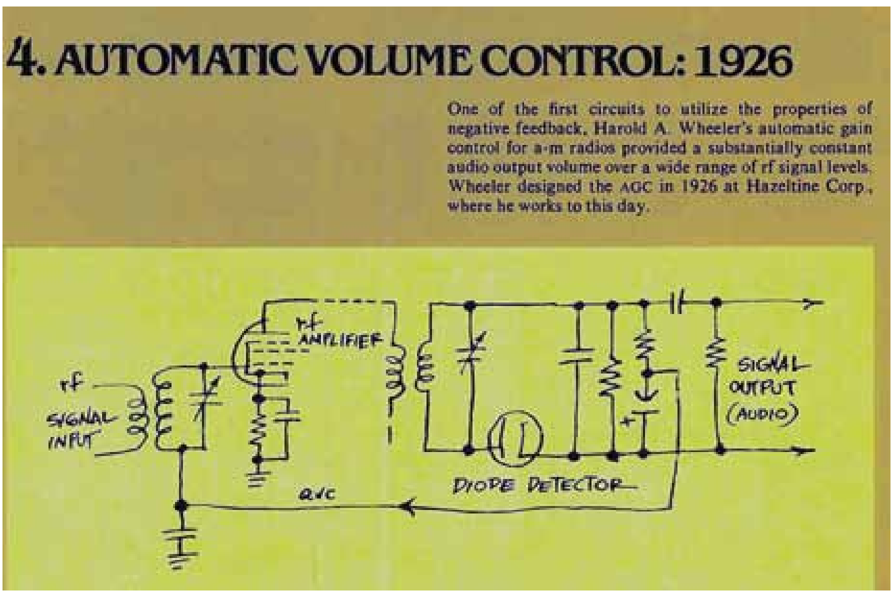

Fig. 25. AVC awarded Classic Circuit # 4. (*Electronics* magazine, Apr. 17, 1980)

The story of Wheeler and AVC covers only a fraction of his long career in electronics. As World War II approached, research for military work became the main activity for Wheeler and Hazeltine Corporation As the war ended, development work on television and color television occupied the laboratories. Wheeler, shown here in 1959 (see Fig. 26), saw an opportunity to pursue other projects by leaving Hazeltine Corporation and forming his own company, Wheeler Laboratories. During this time, he was contracted by Bell Laboratories to perform research in a variety of areas for the defense department. As more time passed and the work from Bell Labs dwindled, Hazeltine Corporation purchased Wheeler Laboratories, and Wheeler would soon become Chairman of the Board and Chief Scientist Emeritus. Wheeler was an advisor to the U.S. Department of Defense as well as a member of the Guided Missile Committee from 1950 to 1953 and served on the Defense Science Board from 1961 to 1964. He received the IEEE Medal of Honor in 1964 for "his analyses of the fundamental limitations on the resolution in television systems and on wide band amplifiers, and for his basic contributions to the theory and development of antennas, microwave elements, circuits, and receivers."

Fig. 26. Harold Alden Wheeler circa 1959. (David Dettinger, Henry L. Bachman, *Harold A. Wheeler's Legacy,* Marconi Advanced Systems Division, 1999, cover picture (edited))

There are not many clues about Harold Wheeler, the man. In written interviews and his writings, he would appear to work in a methodical, engineer-like, manner. His books were carefully divided into sections, subsections, and further subdivisions. His interviews often included many short answers, as if he was appearing on a witness stand, which he did many times in many patent cases. Fortunately, there are some people who can tell us of their personal contacts with Wheeler in his later years at Hazeltine Corporation. Wheeler published monographs that were used by the younger engineers to get them up to speed for the projects that lay ahead.

When Donald Patterson was publisher of *Radio Age* magazine in the 1970s, he wrote an article about Wheeler and contacted him at Hazeltine Corporation. Don was happy to find a man willing to tell his story, and soon Don had a new friend. It led to Don traveling from Georgia to Long Island, New York, to meet Wheeler. At Hazeltine, he found Wheeler in a functional but modest office that served as the center of workstations where scientists and engineers could work on their projects and turn to Wheeler for guidance if needed. Don described Harold Wheeler as a true gentleman, and Don's conversations with Wheeler continued for some time after his visit. After Wheeler retired and moved to California, the telephone conversations continued for some time, as Wheeler enjoyed talking about his days with Hazeltine and his favorite invention, the diode AVC.[35] As the number of phone calls faded away, Don heard of Wheeler's passing on April 25, 1996.

Electronic Design magazine published an article about Wheeler when he was chairman of the board of Hazeltine Corporation (see Fig. 27) that included an interview. He was asked why many engineers never found it easy to do creative work. He replied, "Someone's got to pay them, and it's an exception for management to be receptive to innovation." He was asked, "What qualities must a creative engineer possess?" He replied, "He must be wired the right way. You can't attribute his creative ability to education. He's got to have an inquiring mind, deductive reasoning, and abstract reasoning. Of course, there are two types of engineers: innovative and cook-book engineers, and we need both in our society."[36] It now appears obvious that Harold A. Wheeler was wired the right way.

Fig. 27. Harold Alden Wheeler with the Washington Receiver, circa 1976. (*Electronic Design* Apr. 12, 1976, p. 80)

Endnotes

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About the Author

Mike Molnar took undergraduate courses at Stevens Institute of Technology in the same rooms in the (temporary) Navy Building that had been the office of Hazeltine Corporation and the lab where Harold Wheeler worked in the summers of the mid-1920s. Soon after that, Mike, always wanting to have his own business, undertook a dramatically unsuccessful start of a radio and television business. In the late 1970s, he then started work with nuclear medicine imaging equipment. Since starting his own company in 1984, he has been designing and building nuclear medicine gamma cameras. These specialized instruments have been used at veterinary diagnostic imaging clinics and at universities around the world. To stay balanced, Mike leaves his daily high-tech world to enjoy the after-hours low-tech world of old radios and television. His collection of electronic fossils is over 50 years old and Mike enjoys writing articles and giving presentations on these topics.

Author Mike Molnar (right) and his assistant Lila prepare for the blast from a Leutz Seven Seas radio. They sure wish it had Automatic Volume Control.