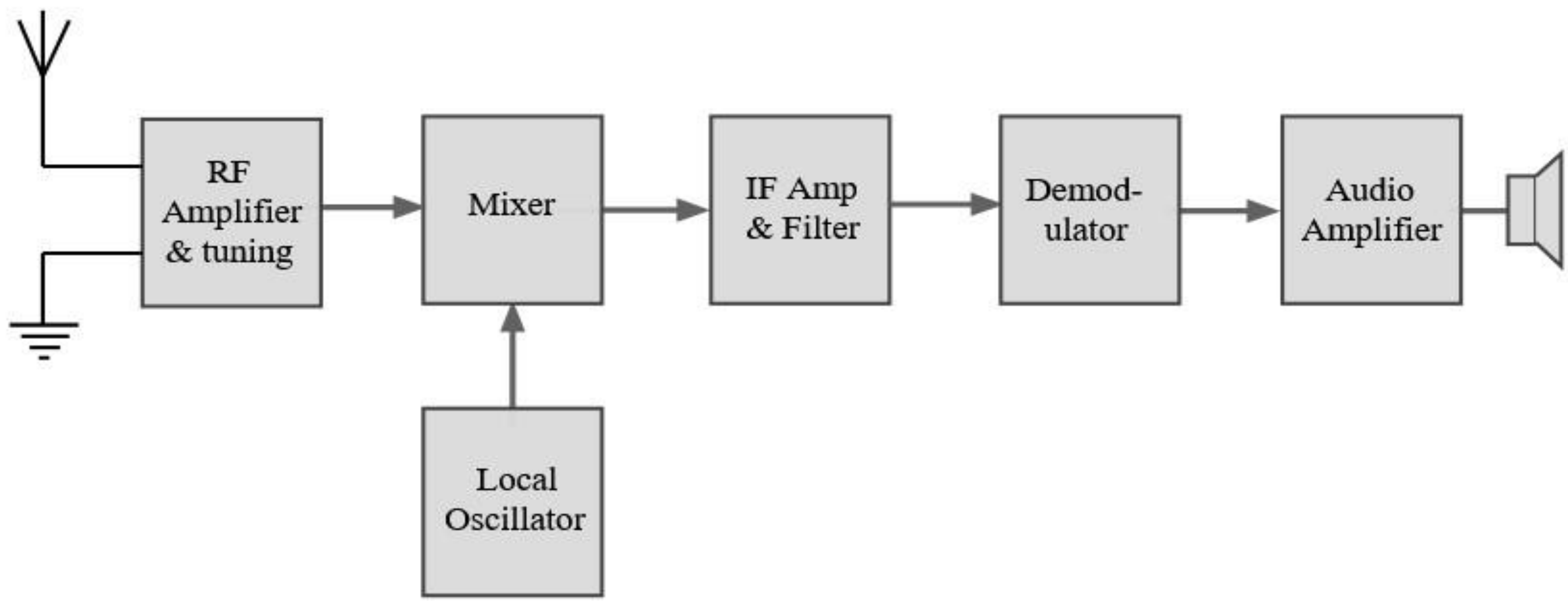
Evolution of the Superheterodyne Circuit and Related Vacuum Tubes

The decisive years 1930 to 1935

MAARC June 20, 2025

Paul Hart

Basic Superheterodyne Architecture



Block diagram of a basic superheterodyne receiver

From a current exhibit on a technical website. This much had been established early in the research and patent process. The challenge was in making it practical.

Some Historical Background

- Lucien Levy was determined the inventor of the basic superheterodyne, Armstrong's patent voided
- RCA was created by US Government in 1920 and 4 US companies. AT&T, Westinghouse, GE and United Fruit
- AT&T had previously bought Levy's patent application - it transferred to RCA
- Armstrong and RCA worked together for many years; Armstrong had a number of patents related to the superhet – RCA bought them
- RCA refused to license superheterodyne patents, first commercial superheterodyne marketed by RCA in 1924
- US Government forced RCA (and its owners) to license patents to other manufacturers in 1930

RCA AR-812

- **World's first commercial superheterodyne receiver**
- **Used 6 UV199 triodes**
- **45 kHz IF frequency**
- **Construction intended to prevent service/analysis**
- **Alan Douglas circuit published in 1996**
- **RCA also continued to offer more traditional radios**

VINTAGE RADIO

By Dennis Jackson

The 1924 RCA AR-812 superhet radio receiver

This was the world's first commercially available superheterodyne radio and a "portable" set to boot – the RCA AG-814 external aerial loop antenna and model 100 loudspeaker puts its total weight close to 30kg! This set uses just six UV199 triodes, with most components tucked away in the "catacomb", a metal container sealed with a wax-like substance (in this case rosin). The intention was to prevent competitors learning about how the radio was designed.

Activities before 1930

- The technical communities knew about the superheterodyne
- Many designs were developed for superhets, which could be sold, but only for construction by individuals
- Commercial production was prohibited, RCA had the superheterodyne market to itself. AC sets introduced in 1927
- By the end of the 20's, the complaints were such that the government sued RCA and its owners for anti-trust violation and forced licensing of the superheterodyne patents. Licensing began in 1930.

Many Articles and Studies Appeared in the Literature

This from Radio News, September 1930

Improving "Super" Performance with the Hopkins

This second article describing the Hopkins Band Rejector System and its application outlines the advantages which may be obtained in superheterodyne performance when the Band Rejector principle is incorporated in the design and construction of intermediate frequency amplifiers. Future articles will describe further uses

MUCH has been said and written of the excellence of the superheterodyne as a broadcast receiver. These receivers have, for the past few years, and in particular those of the "custom-built" variety, been characterized by the unusual degree of selectivity which they afforded as compared to the usual t.r.f. receivers. Large numbers of supers have been sold which embodied moderately low-frequency amplifiers, in which excellence of i.f. amplifier design, accompanied by some considerable assistance from preceding "broadcast frequency" circuits, contributed to the desired end. In the average "custom-built" super, the overall rejectivity to undesired frequencies has been accomplished by means of a rather long succession of tuned circuits in the i.f. amplifier.

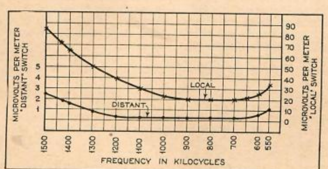
It will be readily seen that, aside from such assistance as is afforded by preceding broadcast-frequency circuits, the burden falls completely upon the i.f. amplifier, and that, generally, the overall performance of the complete super is a counterpart of that of its i.f. amplifier. For this reason, and because of the public acceptance of the super as an excellent receiver, continual investigation takes place into ways and means for the improvement of the characteristics of the i.f. amplifier.

The advent of the "double-tuned" or "band-pass" circuits, and their general use in t.r.f. receivers, immediately suggests, and naturally so, their incorporation into the i.f. amplifier. Such amplifiers have seen widespread use, although it would appear that they were generally of the "insufficiently coupled" type, producing only to a limited degree the benefits expected from a true band-pass amplifier. Their use merely increased the total number of tuned circuits in the entire receiver, producing selectivity of a rather high degree, if selectivity be defined only as station separating ability, without regard for the tendency to greatly attenuate the high-frequency sidebands. Equally good rejectivity is secured by the use of an equal number of cascaded circuits, each containing an amplifier tube, and the latter naturally supplies considerably greater amplification. The degree of damage to the fidelity characteristic, with either method, is greatly a matter of excellence of the individual circuit design and great difficulty is experienced in attempts to avoid such damaging attenuation.

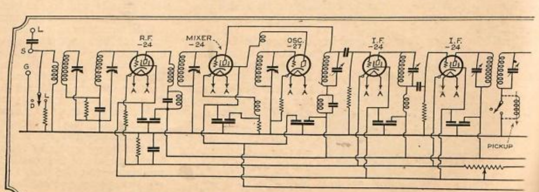
All study of amplifier design would appear to be directed toward the possibility of maintaining sufficiently high rejectivity to insure reception of programs on channels only 10 kilocycles removed from the most powerful local transmitters, and at the same time, without radically impairing the fidelity with respect to the higher audio frequencies, at least those below 5000 cycles. To do this, whether at broadcast frequencies, or in the intermediate amplifier, involves an overall resonance characteristic having almost vertical slope, with as close to a flat top as the designer can produce. This has been referred to facetiously as a "chimney" type of characteristic, and quite probably is as yet unknown to the industry, except with a width so great as to make it useless for the requirement as stated above. There has been offered for investigation recently a new circuit combination for securing a close approach to this much wanted characteristic in r.f. amplifiers. This new arrangement is known as the "Hopkins Band Rejector System." The fundamental elements of such a system, together with some simple curves showing its possibilities, were outlined in RADIO NEWS for August. Its value as an intermediate amplifier will be immediately recognized upon further study. It would appear that the voltage amplification per stage should closely approximate that realized with the simplest type of tuned plate impedance, which in itself would be entirely lacking in the required selectivity; its rejectivity should be that of the ideally coupled "double-tuner," which, however, when so coupled, seriously reduces the effective energy transfer from tube to tube. Further, the band width may be fixed, by design, at a value which will allow the desired station separation, and at extremely high ratios of field strength, with respect to normal.

After lengthy laboratory study of the effects of the numerous design factors involved, the Hopkins system has been chosen for use in the i.f. amplifier of a super, as pictured in these columns. In combination with properly chosen units the system results in such admirable overall performance that some of the design factors entering into the complete receiver are presented, in order to more clearly portray its possibilities.

It is well known to the readers of RADIO NEWS that the



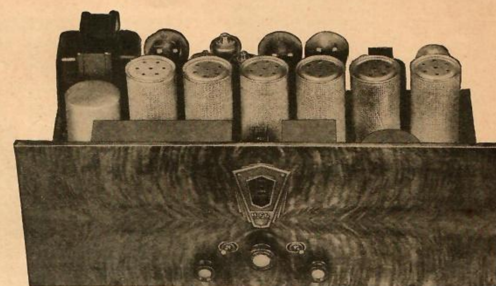
An idea of the sensitivity of the receiver for distance reception over local reception may be obtained from the two sensitivity curves shown above



*High Frequency Laboratories.

Band Rejector System

By E. K. Oxner*

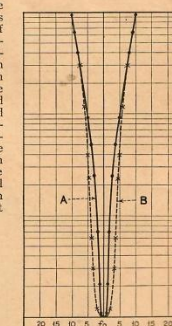


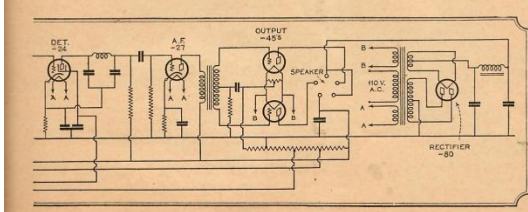
This HFL superheterodyne has been designed incorporating the features of band rejection in its intermediate amplifier, as described in the text

second oscillator beat tuning position found in early supers cannot now be tolerated, and that it has been in the past removed by means of sufficient r.f. tuning preceding the mixer tube. No great selectivity demand was placed on such circuits, as they had only to suppress energy at a frequency removed from the desired channel by twice the intermediate frequency. Another means was used, namely the tuning of the i.f. amplifier to a frequency approximating 475 k.c., which, with a broadcast spectrum 950 k.c. in total width, successfully prevented the second tuning position, by removing it from the range of the tuning circuits of the receiver. With the r.f. circuits preceding the mixer, a choice of i.f. frequencies is offered the designer, and if the use of such r.f. be justified for other reasons as well, greater latitude is permitted in selecting an i.f. frequency at which the maximum benefits are realized.

With the increase in the number of high-power broadcasters, and some of the transmitters located quite near to heavily populated residential sections, carrier modulation or "cross-talk" has become serious. Such interference is being combated in t.r.f. sets by the general adoption of pre-selectors, in most cases coupled below the critical coupling value. At the same time, the spectrum around 475 k.c. is becoming more fully occupied with commercial services, and the power outputs of such transmitters are such as to seriously affect the simple single-circuit input tuning systems generally used with supers of the high intermediate-frequency type, even though such circuits be of the best design. From this, it would appear that the use of broadcast-frequency circuits, preferably with a pre-selector, with or without r.f. amplifiers, is by all means justified.

In the choice of the proper intermediate frequency, many factors are involved. It is well known that the maximum voltage amplification of the –24 type of tube may be more nearly approached at the lower radio frequencies, especially when freedom from the requirement of tuning over a considerable frequency band permits wide latitude in the l.c. ratio of the tuned circuits. For more detailed study of the other factors, the interested reader is referred to I. R. E. Proceedings for March, 1929. The Hopkins amplifiers described herein are tuned to operate at a frequency of 182.5 k.c. At this frequency, with extremely low circuit losses secured by Litzendraht coils of proper form, and with selection of series-resonant choke coils of proper values of effective capacity and low resistance, the amplification per stage is such that but a single "pair" of Hopkins stages is necessary. Examination of the curves in the August issue will disclose the necessity of using the system in properly "paired" stages. In the amplifier described, the Hopkins system is followed by a conventional tuned plate-tuned grid stage, so designed as to completely eliminate the portions of the curve which tend to return above the baseline at some distance from the channel center, yet wide enough in band width as to not affect (*Continued on page 277*)





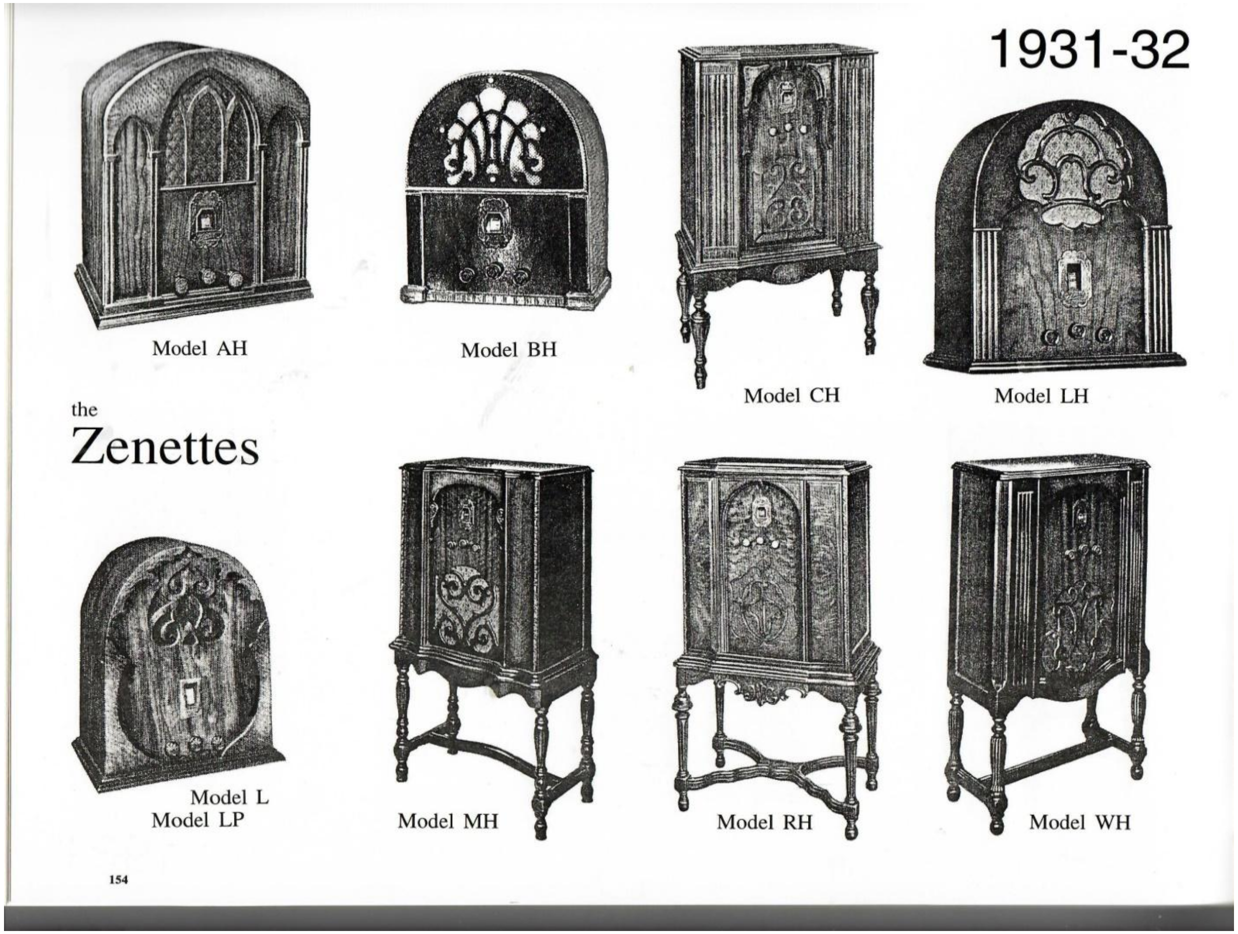
Above, A shows the curve obtained when receiver is adjusted for maximum gain (sensitivity = 1 mv abs. @ 1000 kc.). B shows the curve for best fidelity (by ear) (sensitivity = 3.6 mv abs. @ 1000 kc.). To the left is shown the circuit diagram of the HFL "super"

In 1930, what was needed to develop the modern Superhet?

- **Electrolytic capacitors – first large production of Electrolytic capacitors was at Cornell-Dubilier in Plainfield NJ in 1931**
- **RCA was required to license the patents for the Superheterodyne – started in 1930**
- **Modern and multifunction tube designs to develop more stable circuitry for economical (and exotic) radio production**
- **Effective AVC functionality – H.A. Wheeler IRE, January 1928 (ref. Ed Lyon)**

Licensing of Superheterodyne Patents Started in 1930

Zenith gained access to superheterodyne patents in late 1931

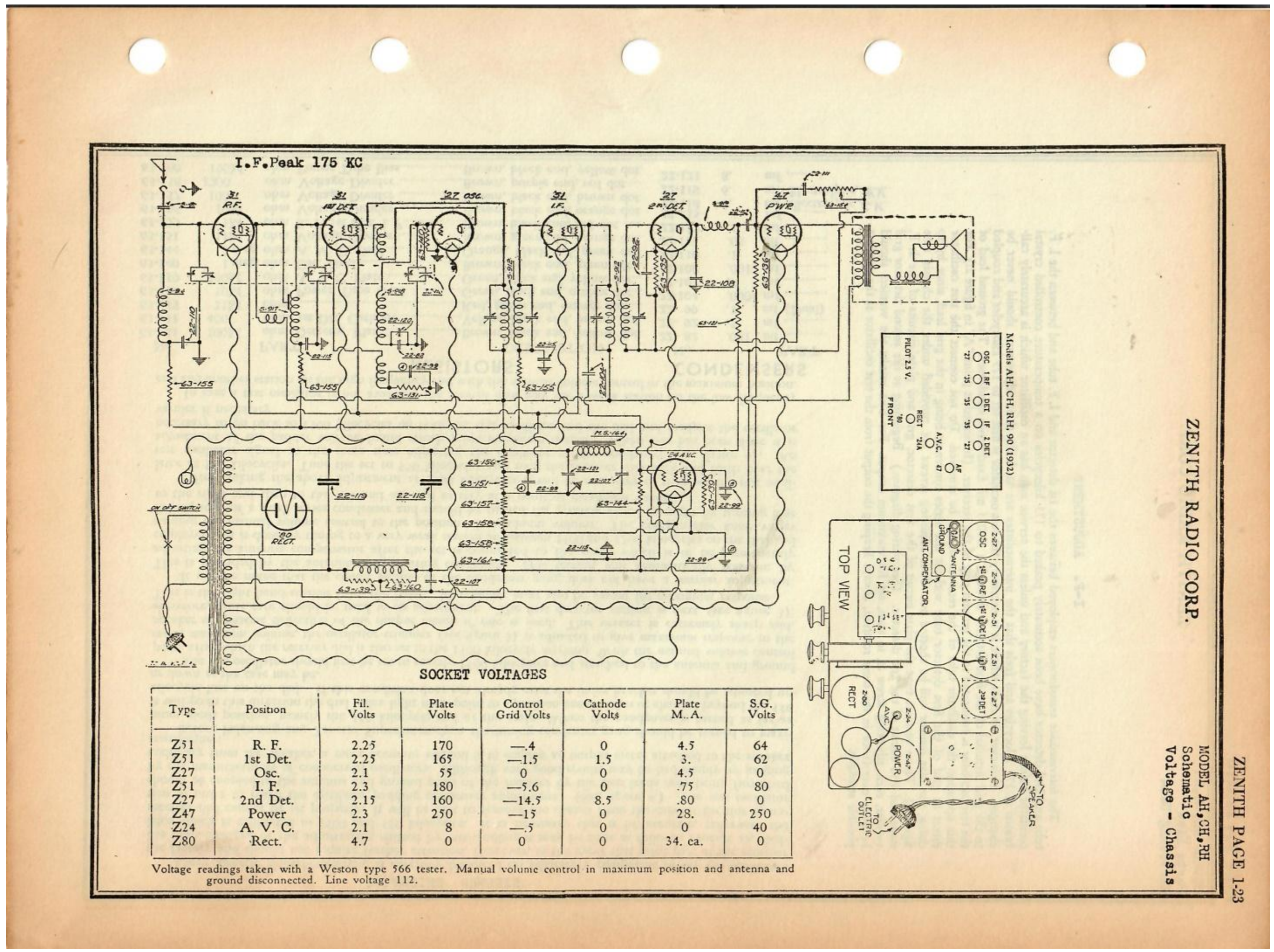


Zenith Had Been Busy!

Release of H suffix models in 1931

Many groundbreaking aspects of their design

- **Rider page 1-23**
- **Development of AVC circuitry using a type 27 AVC tube, a 24 as 1st detector and 3AVC controlled tetrodes**
- **175 KC IF frequency**
- **In 1935, Zenith would introduce the massive Stratosphere**



Type	Position	Fil. Volts	Plate Volts	Control Grid Volts	Cathode Volts	Plate M..A.	S.G. Volts
Z51	R. F.	2.25	170	—.4	0	4.5	64
Z51	1st Det.	2.25	165	—1.5	1.5	3.	62
Z27	Osc.	2.1	55	0	0	4.5	0
Z51	I. F.	2.3	180	—5.6	0	.75	80
Z27	2nd Det.	2.15	160	—14.5	8.5	.80	0
Z47	Power	2.3	250	—15	0	28.	250
Z24	A. V. C.	2.1	8	—.5	0	0	40
Z80	Rect.	4.7	0	0	0	34. ca.	0

Voltage readings taken with a Weston type 566 tester. Manual volume control in maximum position and antenna and ground disconnected. Line voltage 112.

Equipotential Cathode

- **Page from the patent document**
- **"Divorcing the heating agent from that which produces the thermionic activity"**
- **Required advances in many materials**
- **Nicolson AT&T - filed 1915, granted 1925**
- **Type 27 introduced in 1927, the first "modern tube"?**

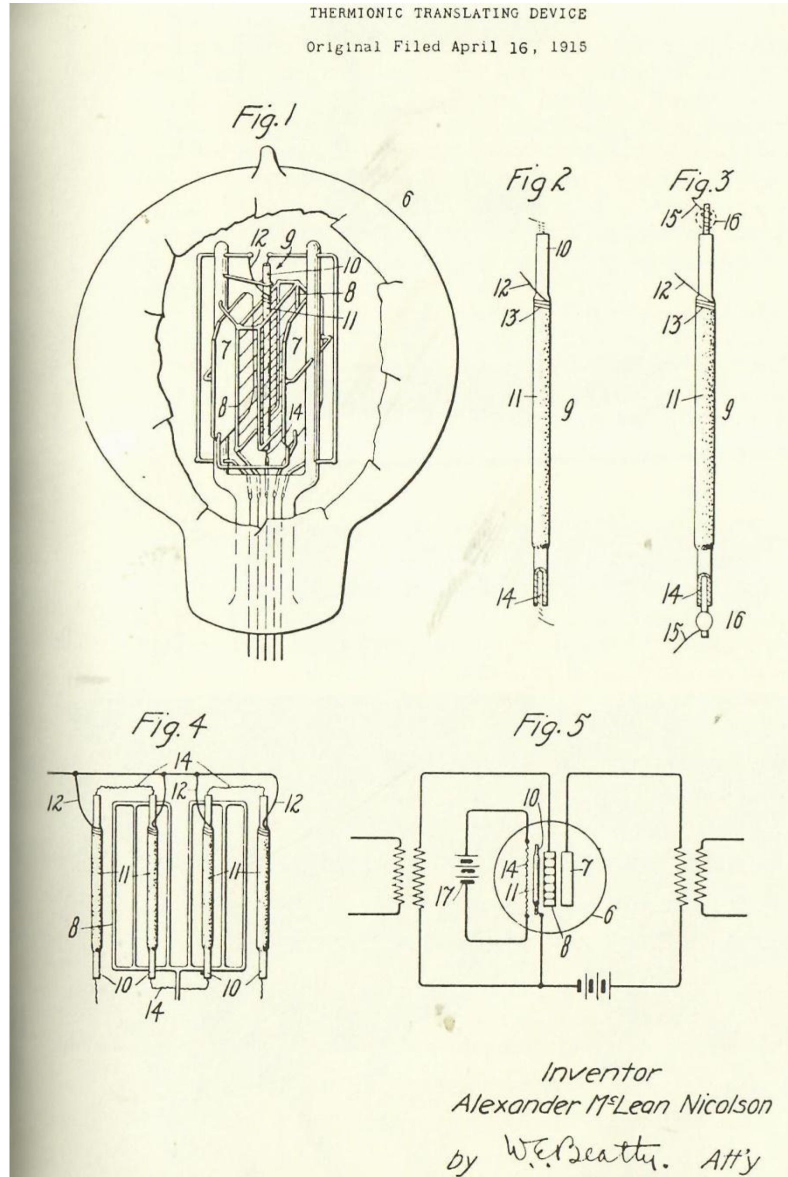


Fig. 8-27. A page from Nicolson's patent on the equipotential cathode.

The Tubes

- **1927 The 27 as the first indirectly heated cathode tube. 71A power amplifier**
- **1929 The 24, first indirectly heated tetrode, sharp cutoff characteristic, tricky to use, but a big improvement over triodes. 45 power amp**
- **1931 35 super control tetrode, 36 tetrode, 37 triode (similar to 27), 39/44 super control pentode**
- **1932 56/76 triode, 57/77/6C6 sharp cutoff pentode, 58/78/6D6 super control pentode**

The Tubes – 1933
A Milestone Year

- **2A3 – "The Mother of High Fidelity"**
- **2A5→42→6F6 power pentodes**
- **2A6→75 high mu triode + 2diodes**
- **2A7→6A7→6A8 pentagrid converter**
- **2B7→6B7 pentode + 2 diodes for AVC**
- **6F7 triode + remote cutoff pentode**
- **41→6K6 power pentode**
- **43, 25Z5, 300 mA filaments for series string**

Massive Releases of new Tube Designs

- Radio Craft article from October 1934
- Rapid releases provided major opportunities and risks for manufacturers and service technicians
- Many early problems for service industry the result of poor design and lack of familiarity with new tubes and circuits

HOW TO USE THE

NEW TUBES

A great many constructors are confused on the correct application of some of the latest tubes. Therefore, we present in this article data on the differences and similarities between the 2.5 and 6.3 volt tubes.

WM. M. PERKINS*

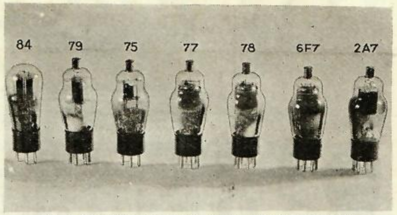


Fig. A. The above are some of the most popular tube types.

THE VARIOUS tubes in these two groups generally referred to as "2.5 V." and "6.3 V." may be compared one with the other and with each other in additional, well-defined groups.

The Triode Group

Starting with the small triode tubes, one finds in the 2.5 V. line the 27 and the 56. The corresponding types in the 6.3 V. line are the 37 and 76. While the 56 and the 76 have identical electrical characteristics, excepting for the heater voltage and current, the 27 and 37 differ slightly. The 37 has a smaller cathode, using less watts than the 27, and has somewhat reduced mutual conductance and plate current, but for all practical design purposes may be considered as essentially the same.

Diode-Triodes

Also, in this group of small triodes, one might add the several tubes which have, in addition to the triode, a pair of diodes. In the 2.5 V. line are types 55 and 2A6. The 6.3 V. line has types 85 and 75 corresponding respectively to the 55 and 2A6. Type 55 has an amplification constant of 8.3, while that of the 2A6 is 100, thus accounting for the differences in voltages and currents used to get the same mutual conductance of 1,100. Where power is not needed, but high gain and high output voltage are desired, the 2A6 is usually used.

* Eng. Div., Nat'l. Union Radio Corp.

Fig. B
The constructor must choose his tubes from over 100 different types.

Non-Variable-Mu Tetrodes and Pentodes

The sharp cut-off (non-variable-mu) tetrodes and pentodes which find service mainly as first- and second-detectors in superheterodynes may be put in one group. In the 2.5 V. line are the 24 and 57 tubes, with the corresponding tubes in the 6.3 V. line being the 36, 6C6 and 77. Types 36 and 24 are tetrodes, whereas 57, 77 and 6C6 are pentodes. The 36 has a smaller cathode than the 24, but with characteristics which very nearly coincide excepting for less watts in consumption in the heater. Type 77, while having a structure quite different from the 6C6, has essentially the same electrical characteristics. The 77 has a shield around the plate, while the 6C6 has a shield above the plate. The use of this outer shield makes the 77 require less shielding in a radio receiver, while, on the other hand, it increases the output capacity which may prove a disadvantage in certain high-frequency circuits.

Variable-Mu Tetrodes and Pentodes

Tubes recommended for service in the R.F. stage, I.F. stage and sometimes first-detector, form a group of pentodes and tetrodes which has a remote cut-off (variable-mu) control grid characteristic, thus enabling one to control gain without introducing distortion or cross-talk. Here again one finds that the 2.5 V. line has fewer types than the 6.3 V. line. In the former group are found only the 35 and the 58. The 35 is essentially a type 24 having a remote cut-off type grid; the 58 bearing the same relation to the 57.

Corresponding to these tubes in the 6.3 V. line are the 39, 44, 6D6 and 78 types. The 39 has less remote cut-off than the 35, having been designed for use in automobile radio sets where the input signals never reach the value encountered in home sets using large aerials. Type 78 has characteristics lying about halfway between the 39 and the 6D6, while the 44 is so similar to the 39 that a tube is now made which replaces either the 39 or the 44 and is designated type 39/44.

All of these tubes, with the exception of the 35, are pentodes, some of them having the suppressor-grid brought out on a separate pin. Another structural difference is that types 58 and 6D6 have a shield above the plate, while types 39/44 and 78 have a shield around the plate.

Special-Purpose Tubes

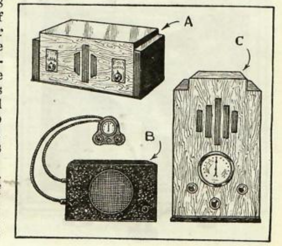
There are several tubes which must be classified as special tubes, or combination tubes—namely, the 2A7 and 2B7 and the corresponding tubes in the 6.3 V. line, namely, 6A7 and 6B7. The 6A7 is a tube for converter use in which certain of its elements constitute the oscillator source. In this tube, the mixing of the oscillator with the input signal is effected solely by virtue of its electron stream and requires no external coupling.

The 6F7 is designed primarily for the same purpose as the 6A7, but must be used in circuits which couple together its triode oscillator with its pentode mixer section. Due to the *complete separation of the pentode section and triode section*, this tube can be used in other circuits, and so, in that way, has a wider field than the 6A7.

Types 2B7 and 6B7 are 2.5 V. and 6.3 V. tubes, respectively, with a pentode section and a pair of diodes. The pentode section is neither a remote cut-off tube, nor a sharp cut-off tube, but lies between. Its use is mainly confined to diode detection and high-gain pentode A.F. amplification, although, in other uses, such as pentode I.F. amplifier and diode detection, it is sometimes a convenience.

(*Continued on page* 250)

Fig. C
A—the midget, B—the auto-radio, and C—the standard receiver—all employ tubes especially designed for each.



RCA Announcement of "New all-metal radio tubes" 1935

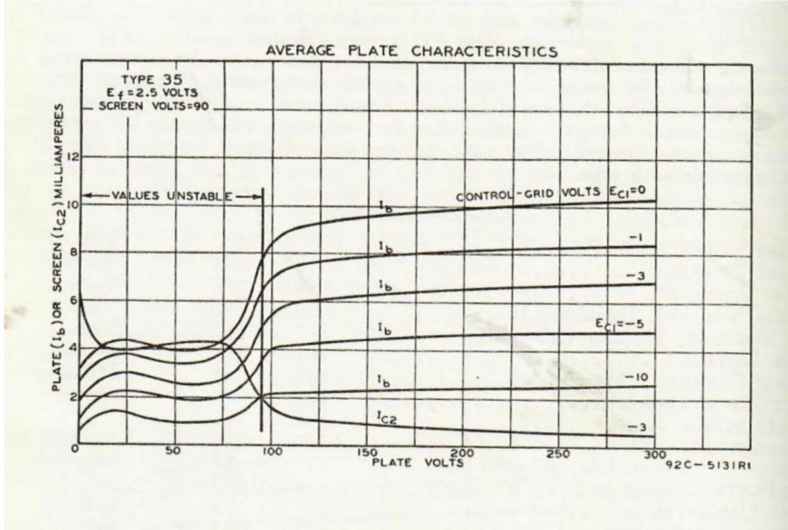
First types:

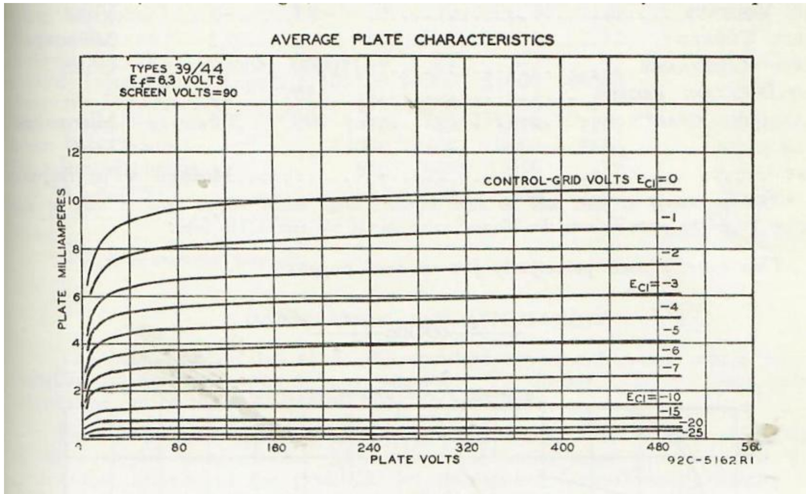
- 5Z4
- 6A8
- 6C5
- 6F5
- 6F6
- 6H6
- 6J7
- 6K7
- 6L7

Tetrodes → Pentodes

Tetrodes (35/41) had a screen grid, but also the tetrode area of instability in plate curves. Remote cutoff. 24, 36 were sharp cutoff tetrodes. Short lived.

Pentodes (39/44) added a third grid which eliminated the area of instability. This one is also a remote cutoff control tube 58, 78, 6D6, 6K7.

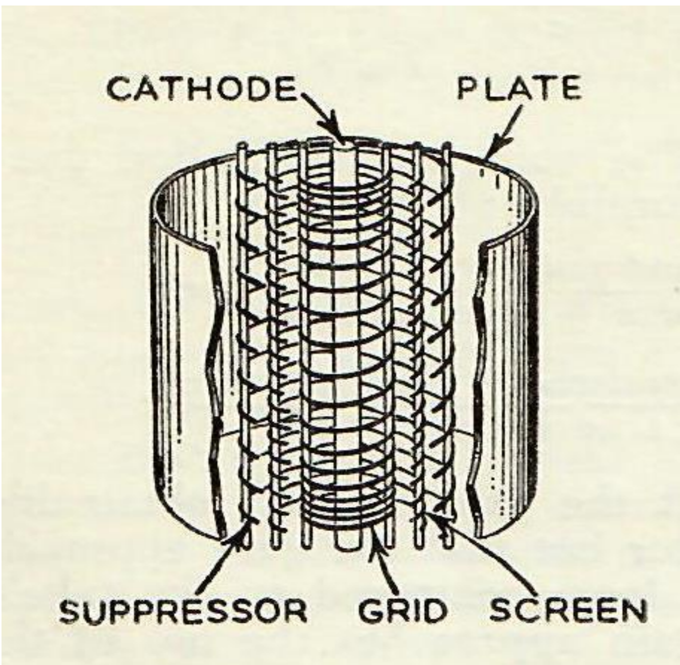




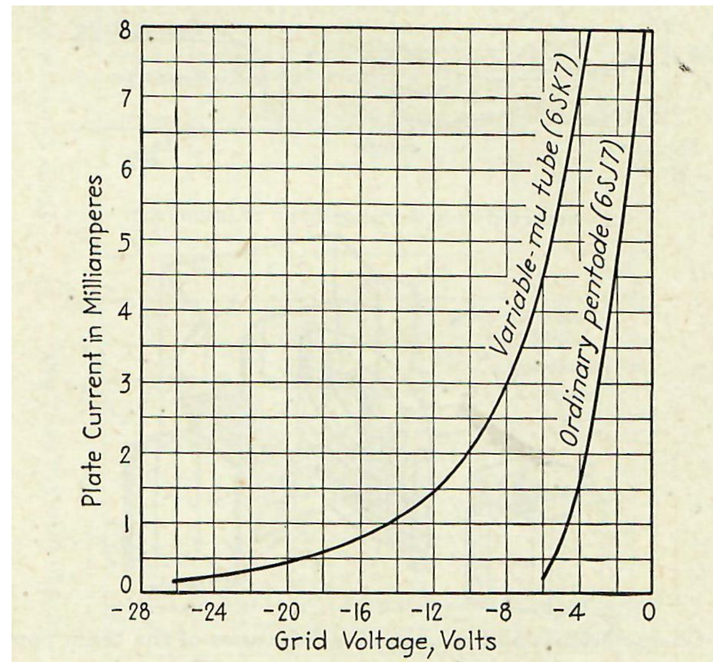
Great Advance for Effective AVC

"Super Control" – Variable mu pentode

Note non-uniform winding of the control grid



Delayed cutoff of the variable mu tube allows for smooth AVC operation



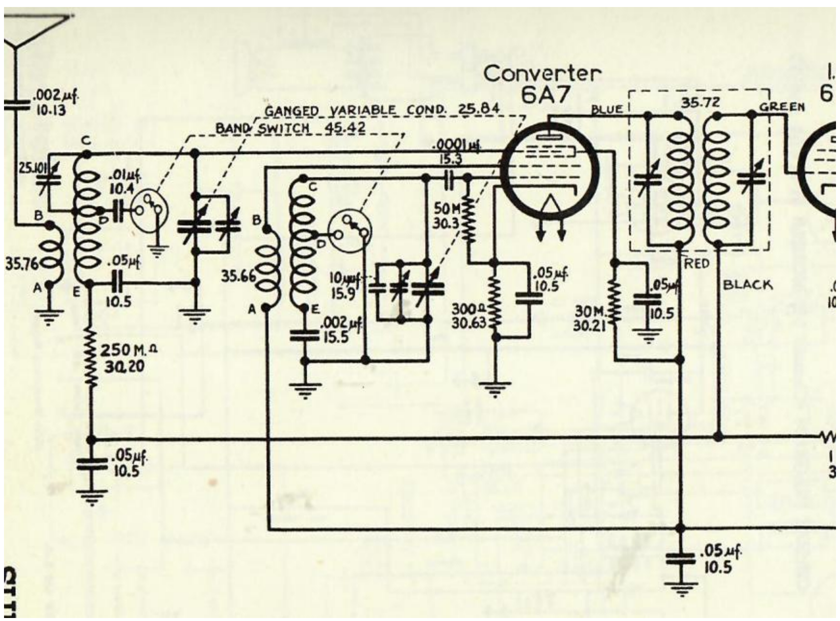
Credit H. A. Snow and Stuart Ballantine 1930

Photo of a 6K7 Control Grid

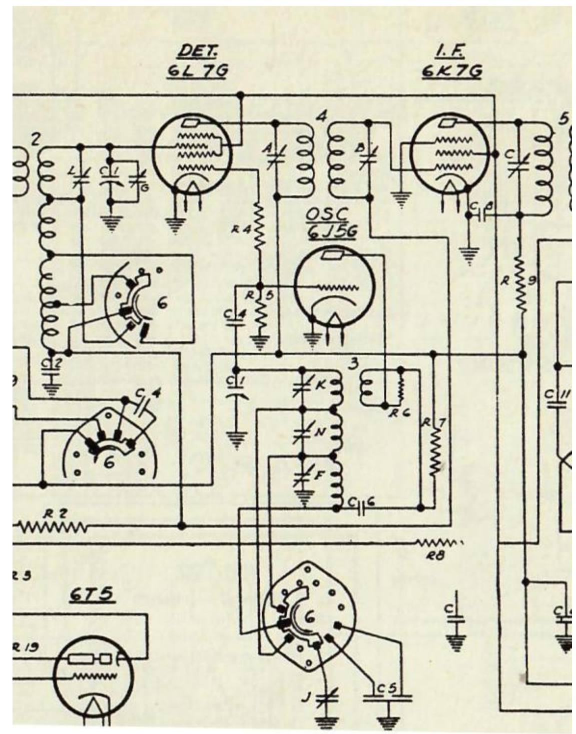
- Reality not quite like the illustration
- Small area of increased pitch near the center
- Pitch distance overall more than for a 6J7 which had a uniform shorter pitch over its entire length

Mixer/Oscillator
(First Converter)

Single Tube Mixer/Oscillator
2A7, 6A7, 6A8

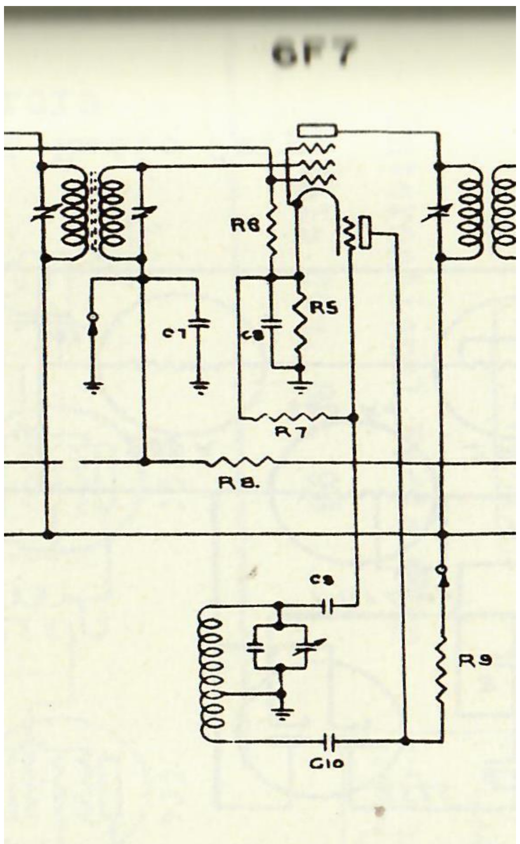


Separate Mixer/Oscillator
Pentode or Converter as Mixer
(6L7 + 6J5 typ.)

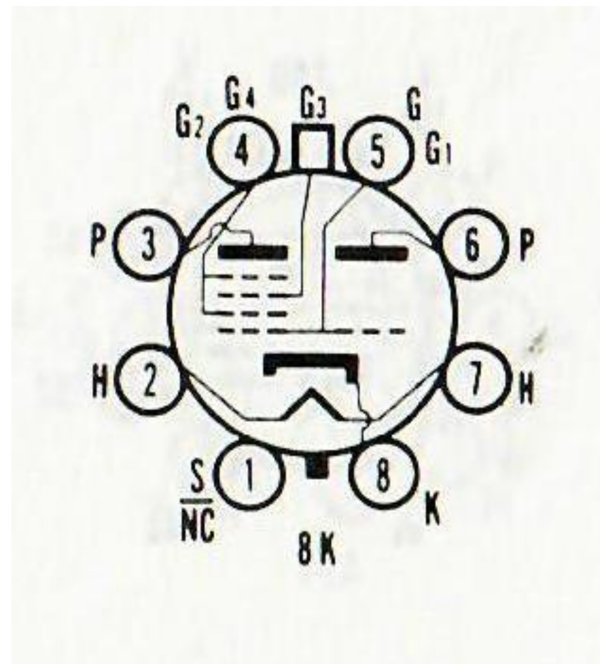


Triode + Pentode, Hexode

6F7 Triode/Pentode
Common Cathode
Hallicrafters Sky Buddy



6K8 Triode/Hexode Converter
Great upgrade for conversions
From 6A8 and battery tubes
1938



Effects of Various Types of AVC

- **Simple AVC (b), most commonly encountered in smaller radios**
- **Delayed AVC, control improves as more tubes are controlled**
- **Zenith used delayed AVC in many of their radios and some unusual combinations**
- **Delayed and amplified AVC including QAVC in top of the line Stratosphere.**

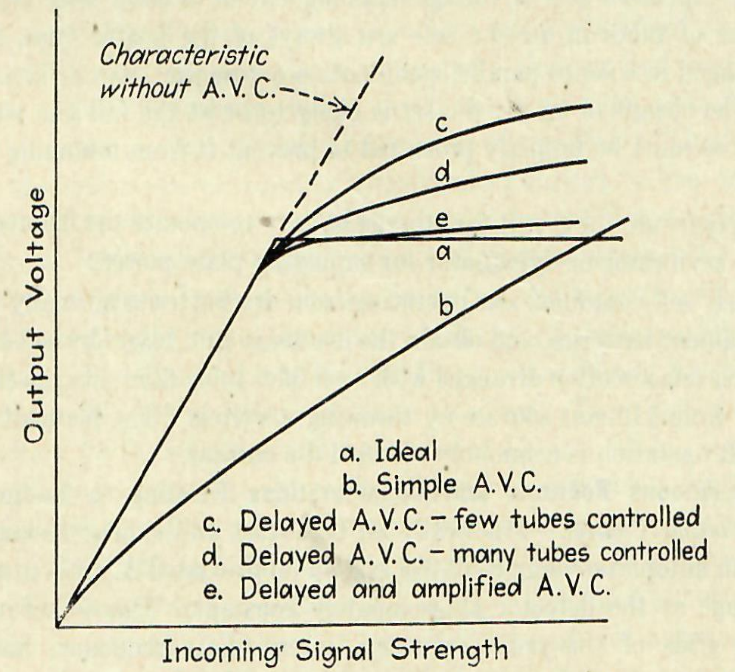


FIG. 12.—Automatic-volume-control characteristics under different conditions.

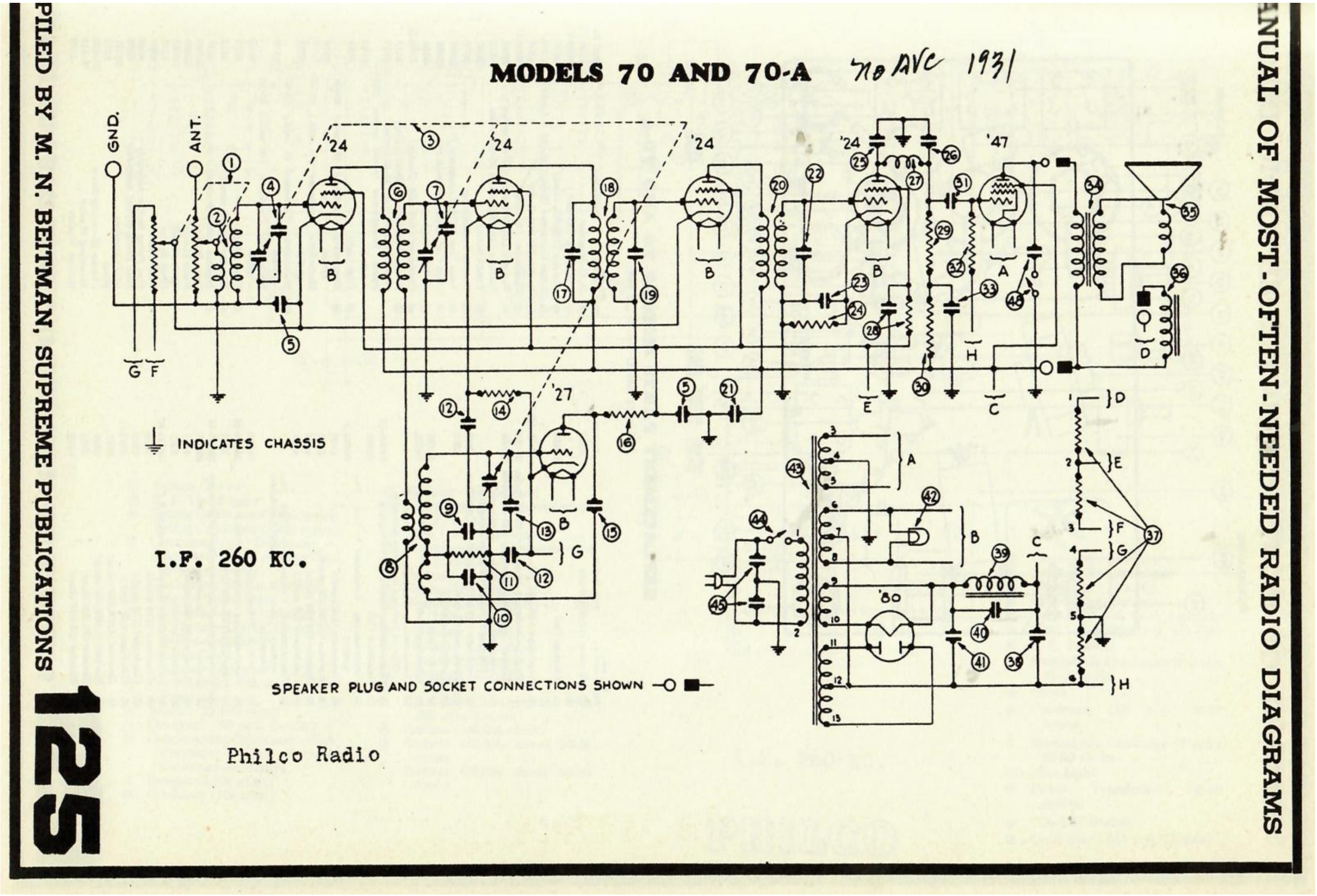
Terman, Radio Engineer's Handbook 1943, Electronic and Radio Engineering, 1955

Philco 70/70-A no AVC 1931

No AVC
Early Model 70/70-A

Type 24 tetrodes and separate 27 oscillator

Plate detector generates no DC signal for AVC



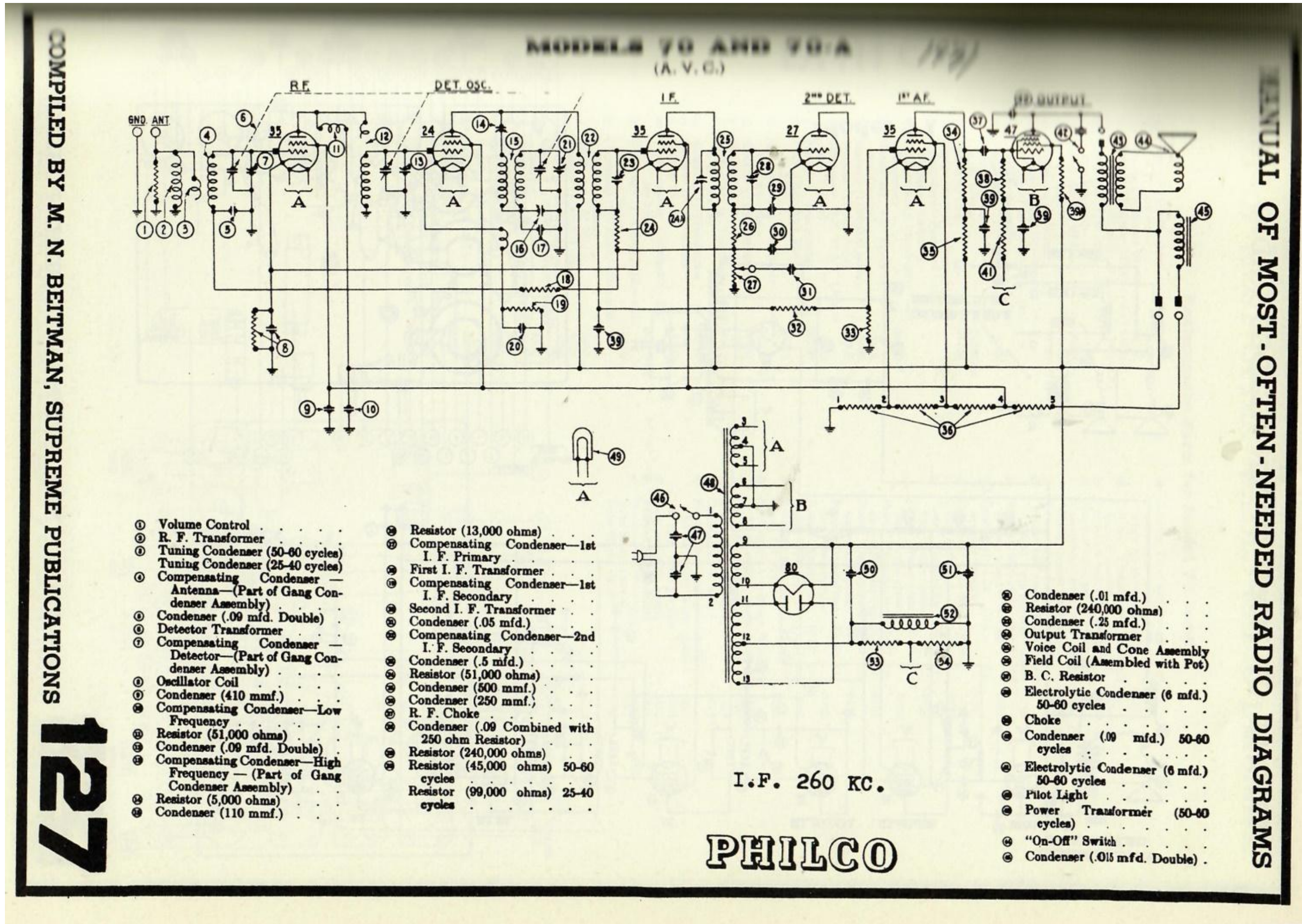
Philco 70/70-A with AVC 1931

AVC added
Later Model
70/70-A

24 serves as
converter
oscillator

Grid detector
generates DC signal
for AVC

Control applied to
RF and IF amp 35s
but not the 24

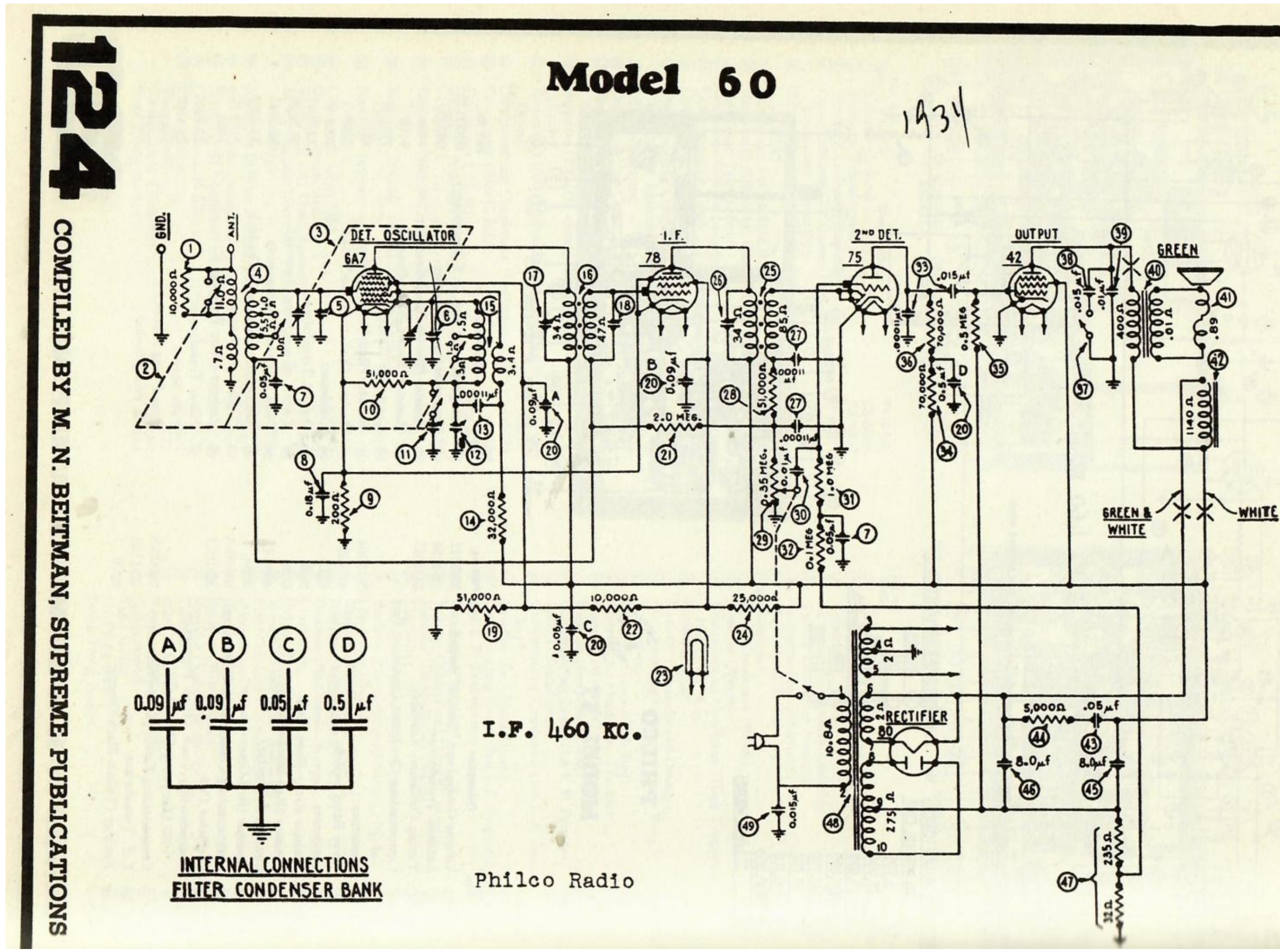


Philco Model 60 1934

Philco 60 1934

Modern circuit with basic AVC
460 kHz IF

Slight + biasing of the 75 is unusual - typical of Philco practice at the time.



Rapid Evolution of Vacuum Tube Design to Improve Receiver Characteristics

Bro. Patrick Dowd, 1978

- **Chart shows estimated release dates of tubes. Many will have been released the year previous to that shown.**
- **Note 27 and 80 in 1927, 24 in 1929**
- **1931 shows rapid release of tetrodes, then pentodes. Obvious cooperation between circuit and tube designers**
- **1932 releases - beginning of modern tube designs**
- **1933 shows massive releases including the 2A7, 6A7, 6F7 + 2A6, 55, 75**

1925
WX-12
UX-112
UX-120
UV-196*
UX-199
UX-200
UX-201-A
UX-210
UX-213
UX-216-B
UX-874
UV-876*
UV-877*

1926
UX-171
UX-200-A
UX-225
UX-288
UV-886*

1927
UX-112-A
UX-171-A
UX-222
UX-226
UY-227
UX-240
UX-280
UX-281

1928
UX-250
UX-859
UX-864

1929
UX-245
UY-224
RCA-221

1930
RCA 230
RCA 231
RCA 232

1931
RCA 233
RCA 234
RCA 235
RCA 236
RCA 237
RCA 238
RCA 239
RCA 247

1932
46
56
57
58
82

1933
1A6
2A3
2A5
2A6
2A7
2B7
5Z3
6A4-LA
6A7
6B7
6F7
12Z3
25Z5
1
1-V
19
39/44
41
42
43
48
49
53
55
59
75
77
78
79
83
84
85
89

1934
1C6
6A6
6C6
6D6
76
84/6Z4

ANNUAL RECEIVING TUBE RELEASES BY RCA (CUNNINGHAM) 1925 THRU 1934

On the left is a list of the RCA (Cunningham) Annual Receiving Tube releases from 1925 thru 1934. The tubes listed for 1932, 1933 & 1934 are taken from the RCA Receiving Tube Manuals (RC 10 - 1932, RC 11 - 1933 & RC 12 - 1934). Company Tube Manuals are excellent for obtaining a complete list of tube releases on an annual basis. Unfortunately, the Tube Manual's year of accuracy does not generally correspond to the calendar year. The Tube Manuals, at least during this period, were published about mid-year. These were prepared and sent to press probably some months prior to publication. Label changes and tube releases after the publication may not have been recorded. These facts must be considered when using this list. For example: A tube may be pictured in the Tube Manual with a label it was never released under or a tube listed as a new release in the 1934 Tube Manual may show up with a 1933 date.

Notes: The UV Tubes listed have brass bases. (*)

UX-225, UX-859 & UX-288 — limited production.

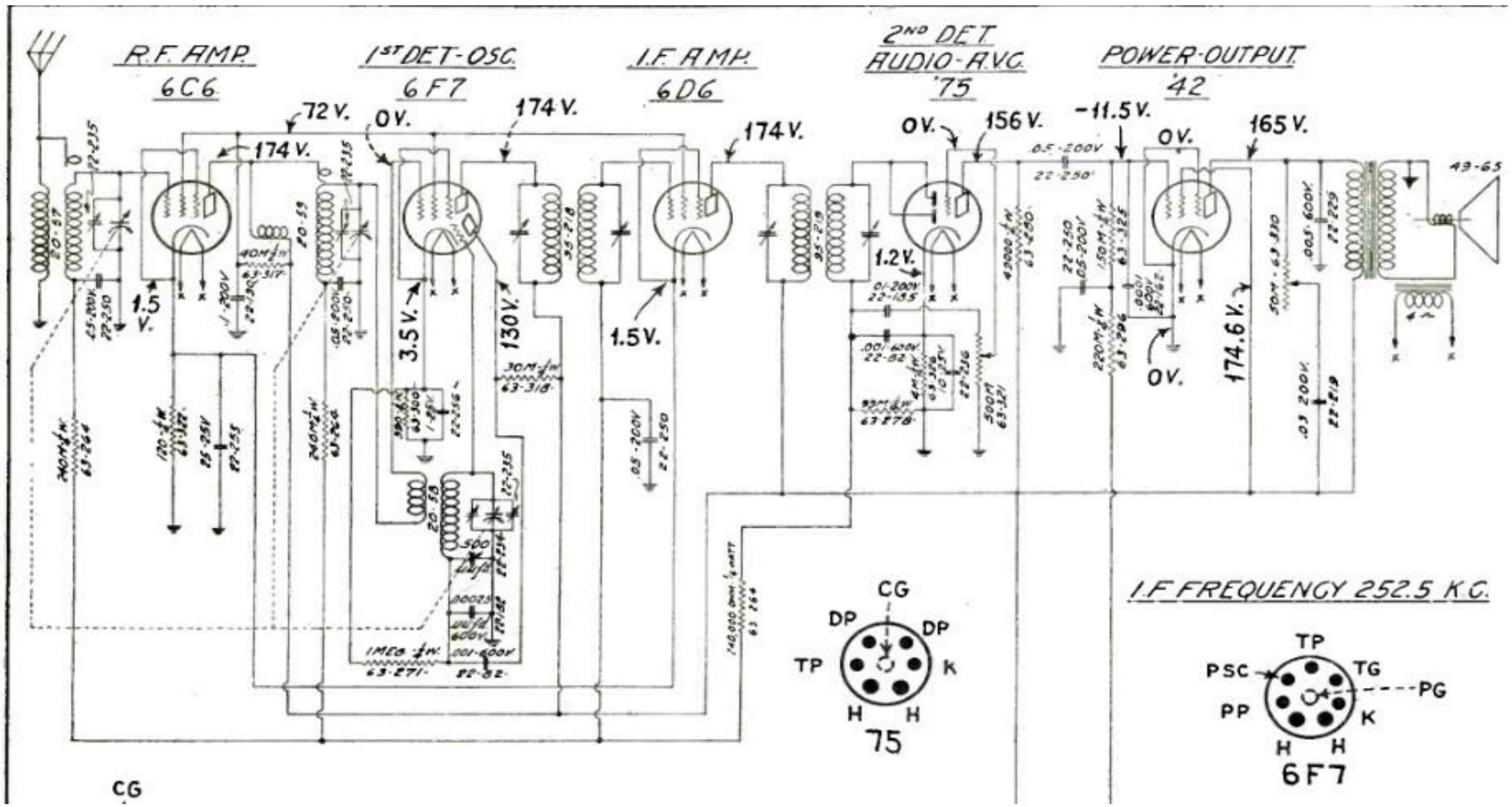
UV-196 — specialized use — limited production

RCA 221 — manufactured for export only.

- 11 -

Zenith Model 462 Car Radio

From March 1934 Sylvania Service Publication

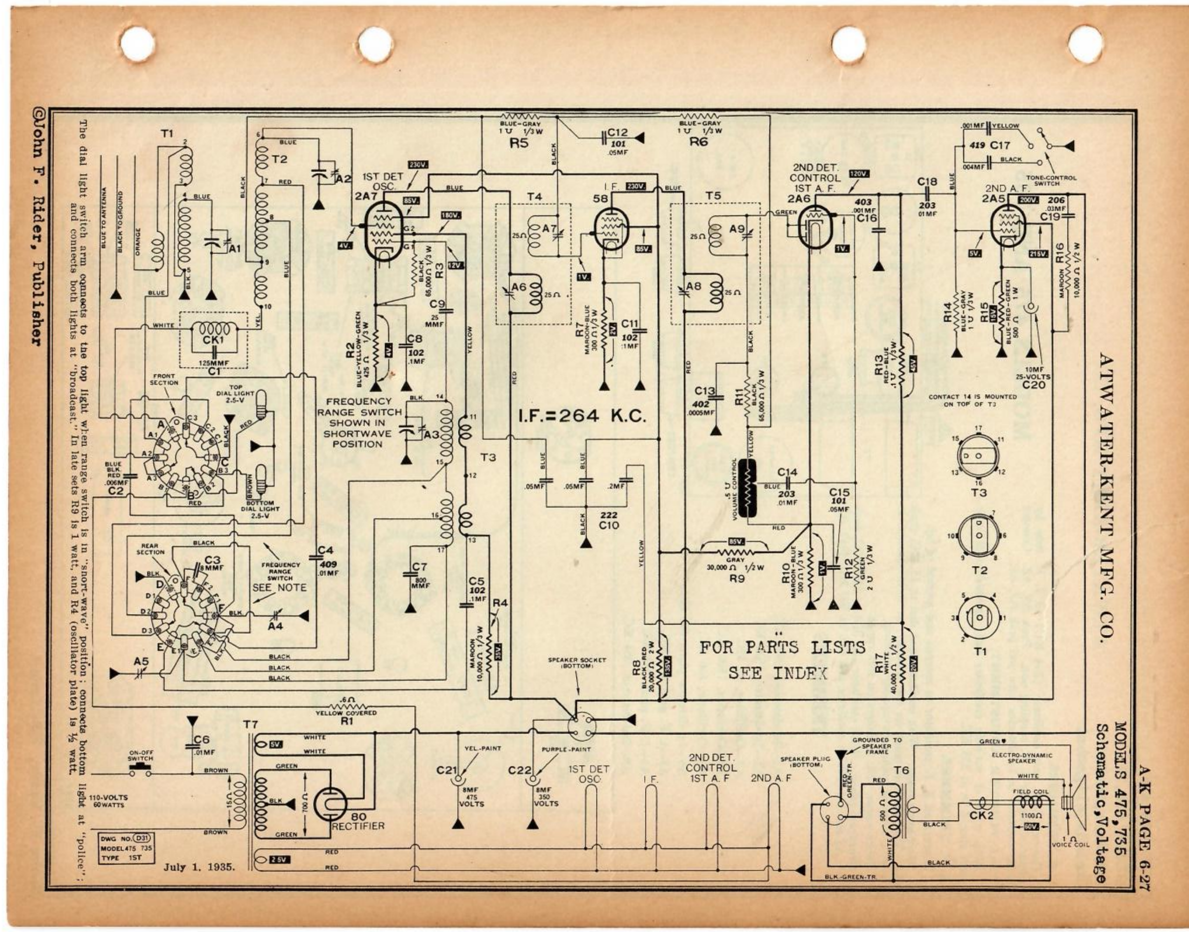


Atwater-Kent 735 July 1935

This design shows the fully mature circuit structure for the 5 tube superhet virtually universally adopted through to the end of radio production.

Key Elements

- **2A7 single tube converter. (6A7, 6A8)**
- **Adoption of 264 kHz IF frequency. Soon increased to 455 kHz to minimize images**
- **58 IF amp. (78, 6D6, 6K7, 6SK7)**
- **2A6 triode, 2 diodes. 1st audio and detector + AVC (75, 6Q7, 6SQ7)**
- **2A5 power pentode output. (42, 6F6). Beam power. successors in 1936 – 6L6, 6V6.**



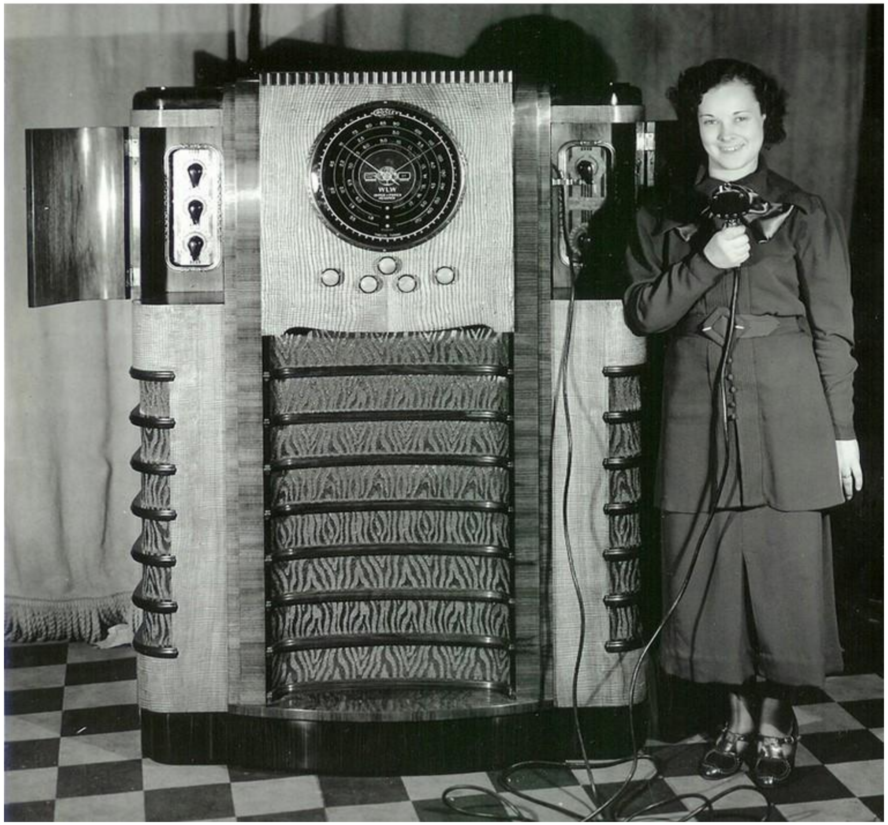
Joe Koester
1000Z
Stratosphere

See Radio Age October 2024, page 14

Snowshoe, the ultimate copy cat!

Wretched Excess

CROSLEY RADIO CORPORATION’S 1936
“WLW MODEL SUPER-POWER RADIO
RECEIVER”



On to the Future

- **Many new tube designs were to follow, as well as enhancements of receiver design, as well as incredibly varied uses. Many were continuations of the technology established by 1935.**

- **Onward to 1941, WWII, radar, magnetrons, TV all sorts of power tube designs and control tubes.**

- **Home receiver designs were enhanced, but with very few changes, endured basically unchanged until the days of ICs, due to the remarkable developments in the time frame 1930 to 1935.**

Circuit Perspective

- For reception of the 540 kHz signal, the oscillator is tuned to 995 kHz.
- Both desired 540 kHz signal and image from 1450 kHz are present at the input
- Each signal produces a 455 kHz result

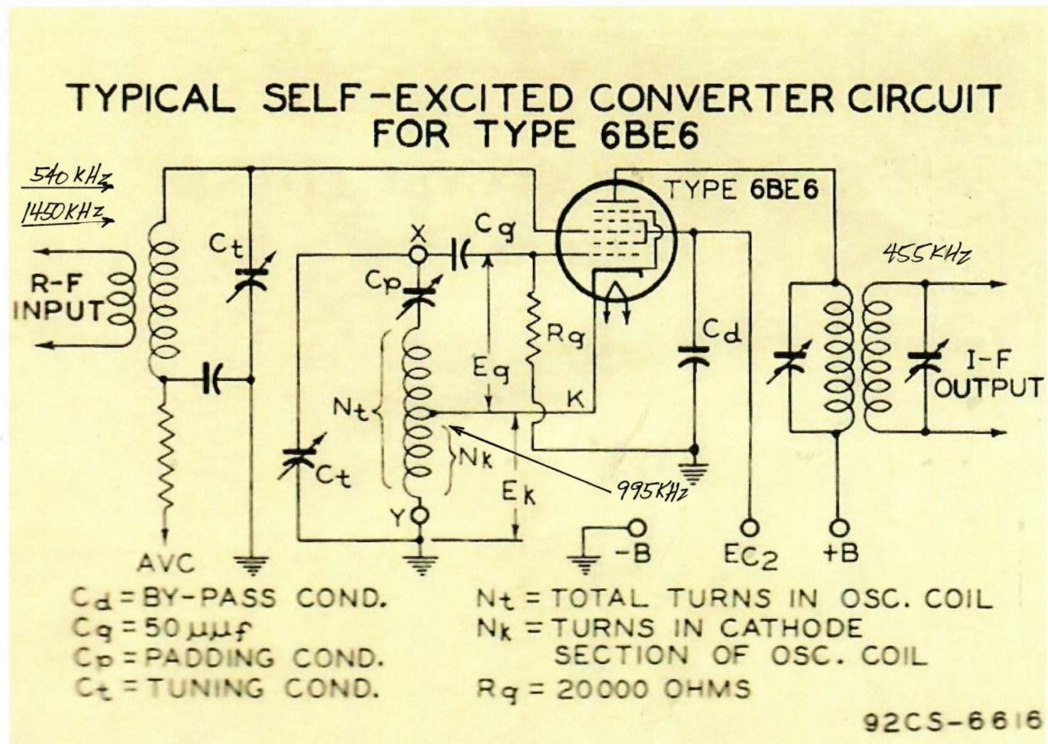
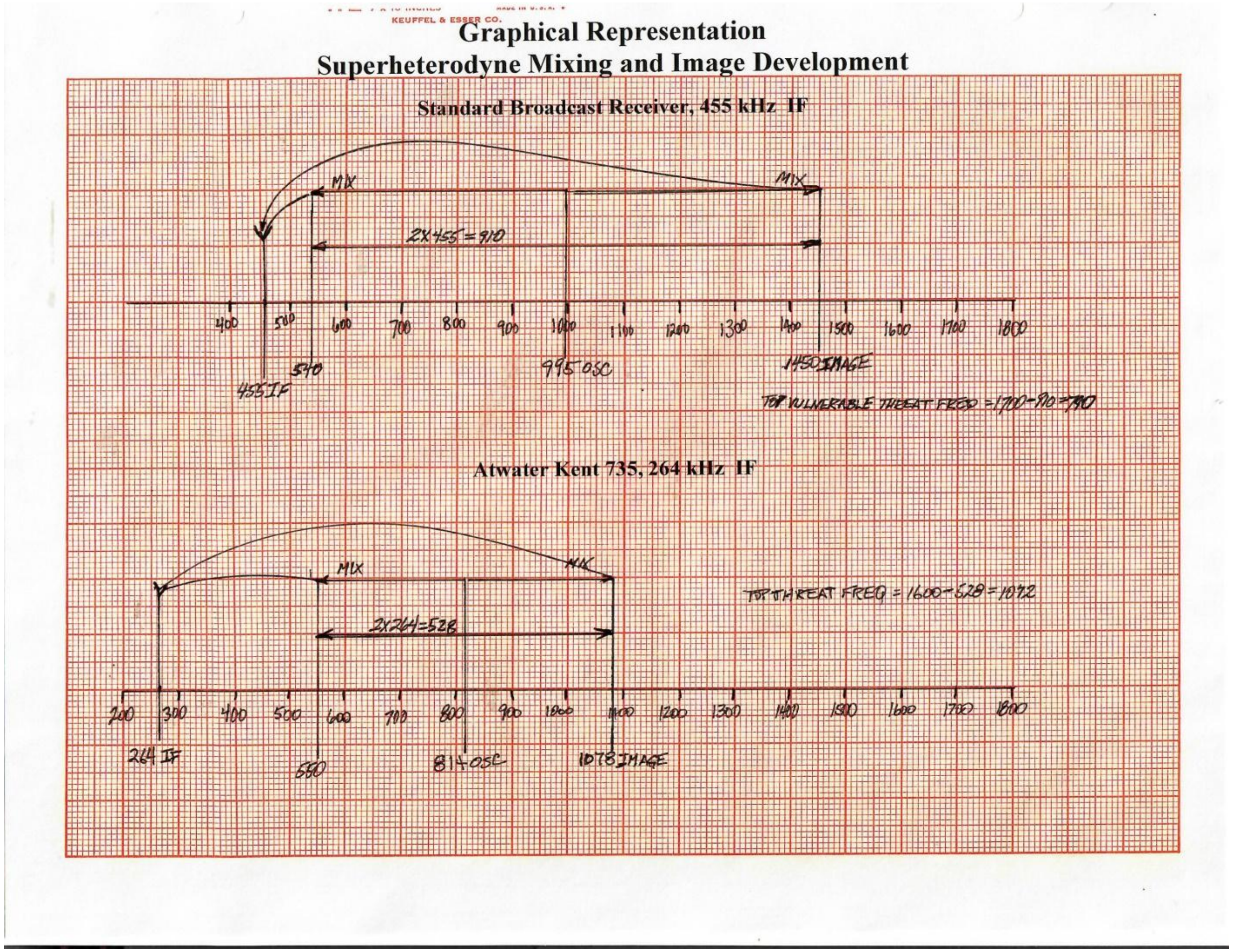


Image Generation Graphic

For 455 kHz IF, Image frequency is 2x455= 910 above tuned frequency

For 264 kHz IF, Image frequency is 2x264=528 above tuned frequency



Wrapping it up

Thanks for your attention

Questions?

Copies of the slides available

Make sure to hear Ed Lyon tomorrow

Full size version available:

Send a message to me with MAARC Slides in the subject

Paul Hart

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