

WESTERN ELECTRIC TUBES: SOME INTERESTING AND HISTORIC TYPES

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INTRODUCTION

Western Electric products have a strong following among tube and equipment collectors. This article discusses some of the electron tubes designed (primarily) by Bell Telephone Laboratories and produced over a 50-year period by the Western Electric Company. Some of these items are of interest because of the technology in the devices themselves; others because of the applications in which they were used. Many are relatively unknown outside a particular industry sector that used them.

This discussion cites particular families of devices and gives examples of early tubes in those families. A tube "comes to life" in the context of the systems in which it was used. However, it is impractical to attempt to analyze each of the 270 or so products that Western made. As regards WE tubes up to 1930, this article does not attempt to duplicate the excellent treatment produced by Tyne [1].

THE MARKET

These tubes had a long history in the electronics industry but were sold only in specialized "niche" markets: the Bell System telephone companies; other telecommunications operations like the railroads' communication departments; military agencies, especially during the two world wars; and the broadcast industry up to the late Forties. Other specific markets in which WE equipment and tubes were sold included professional audio systems (motion-picture sound, paging and public-address systems, audiometers, hearing aids), aeronautical radio (both airborne and ground stations), ship-to-shore radio, and a brief venture, ca. 1946, into radars for ships. "Western" held, between 1930 and about 1950, a strong position in mobile radio (railroad, aeronautical, public-safety; both vehicle and base stations). There was a line of power tubes with capabilities up to 250 kW for AM and FM transmitters, but WE seems never to have tried to enter the industrial RF-heating market that the other power-tube vendors opened up in the Forties. With the exception of some broadcast receivers sold in Canada by Northern Electric, there was no attempt to penetrate a mass market.

The entire Bell System used only about 250,000 tubes in 1930, compared to roughly 65,000,000 in broadcast radios. But WE tubes were routinely lasting 10,000 hours, at a time when RCA and other makers were advising radio owners to re-tube completely each season. By 1940 Bell usage had grown to 1,250,000, still tiny compared to about 700,000,000 in entertainment uses. Thus the market for tubes of telephone quality, essentially all of it in WE's hands, was sizable but hardly massive.

THE DESIGN ENVIRONMENT

The designers of WE tubes were free from many of the competitive pressures and "fashion" trends prevalent in the consumer-electronics industry. They innovated at their own pace: slow to adopt the octal base in the Thirties, they developed whole families of devices with remarkable speed under wartime pressure, and later had Compactron-style designs in production some years before GE introduced the Compactron to the consumer market. They were apparently unimpressed by RCA's efforts to promote the metal tube in the 1935-38 time frame; the only metal WE tubes were klystrons like the 723A or 2K45. They had little need to develop six-volt types until the late Thirties; indeed, most of their early applications used series filament strings wired to the 24-volt battery supplies in telephone offices. Remarkably few multiple-unit tubes came from Western: only the obvious full-wave rectifiers (274A, 301A, 314A, 345A, 351A, 422A), a duo-diode-triode (352A), and some twin triodes (396A/2C51, 407A, 412A, 420A, 421A). Unlike the smaller general-sales manufacturers, WE did not need to introduce new types or repackage old ones in hope of opening up a market slot. A Western tube was often optimized for a unique application for which no broad-market device ever became available. The product line at one time or another included the usual receiving-type tubes, klystrons, high-power transmitting tubes, thyratrons, traveling-wave tubes, cold-cathode diodes, VR tubes, 4-GHz triodes, cathode-ray tubes, and -- for wartime radars -- magnetrons and TR switches.

The major design requirements were to produce interchangeable, reliable, and long-lived devices. It was expensive enough for a telephone company to replace a failed tube in a microwave station, snowed-in on a mountain top 200 miles from the nearest maintenance center; it would have been disastrous to have to repair the outage of a submarine-cable repeater, say, 1000 miles east of Newfoundland in midwinter. Thus reliability requirements, Telco or commercial, ranged from demanding to extraordinary. Fortunately, many of these devices operated in benign environments. In the typical telephone application, the tube was rarely cycled on and off and the supply voltages were regulated closely. Tubes and equipment were designed by the same firm; there

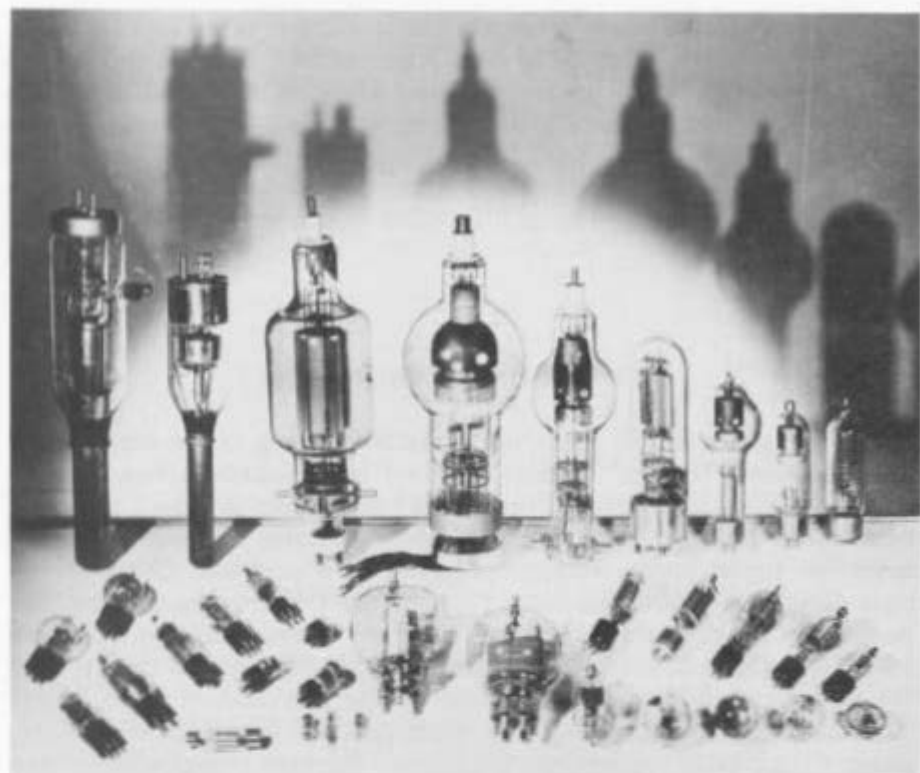


Fig. 1. Representative WE tubes ca. 1944, with their plate-dissipation ratings. **Rear row:** power triodes and mercury rectifiers. Left to right: 340A water-cooled, 25 kW; 228A water-cooled, 5 kW; 279A, 1.2 kW; 266C, 10 A forward and 22 kV reverse; 255B, 4 A forward and 20 kV reverse; 308B, 250 W; 315A; 267B; unidentified. **Bottom left:** two tennis-ball repeater tubes, probably 101- or 102-type; unidentified; 307A pentode, 20 W; 393A thyatron; unidentified; 310B. **In triangular formation:** 313C cold-cathode diode, 717A pentode; 6AR6 beam tetrode. **At bottom:** 1B22 radar TR tube, for fuse-clip mounting; three unspecified miniature and subminiature tubes, probably including the 362A hearing-aid pentode. **Center:** 357B triode, 350 W; 701A radar-pulsar beam tetrode, 100 W. **Bottom right, upper row:** 300B triode; three unidentified; rectifier, probably 3B24. **Bottom right, lower row:** 715C radar-pulsar tetrode, 60 W; 316A doorknob triode; two other doorknob tubes probably including 368A; D156548 triode.

Photo: AWA Museum.

was little incentive to push a tube beyond its ratings as might occur in entertainment equipment.

Western Electric equipment did not necessarily use WE devices. The 23A broadcast console, ca. 1935, used six-pin receiving tubes (42s, an 83V, 1603s, and 1609s) from any maker. The 25B speech-input equipment of 1947 could use Western or ordinary types (348A or 6J7, 349A or 6F6, 351A or 6X5, etc.). Certain items like the 21A transmission measuring set used a mix. Most WE-built military systems employed commercial tubes wherever suitable ones were available. But such cases were unusual.

SECOND-SOURCING

A number of other makers made tubes of WE types, either under license or as commercial equivalents, primarily for the audio and radio-transmitter markets. As will be described in more detail below, there were a number of near or exact substitutes, and a number of types with dual general-market numbering. This was particularly true of post-1942 devices used in military systems. Table 1 lists a number of these cases.

TABLE 1
NEAR OR EXACT EQUIVALENTS OF WE TUBES

SIMILAR TYPES		DUAL-NUMBERED	
WE Type	Industry Type	WE Type	Industry Type
211D	211	376B	5589
242B	211	396A	2C51
261A	835	397A	2K56
274A	5Z3	398A	5603
274B	5R4GY	401A	5590
289A	4B26 or 2000	403A	6AK5
295A	203A	403B	5501
300B	2A3	404A	5847
304A	834	408A	6028
322A	803	409A	6AS6
348A	6J7 or 1620	416B	6280
349A	6L6G	417A	5842
350A	807	420A	5755
350B	6L6G	421A	5998
351A	6X5G	443A	6388
422A	5U4GB	707B	2K28

NUMBERING

Western Electric did not attempt to encode information into the numbering of its tubes. As reported in Tyne, some early 2xx-series devices sold outside the Bell market were new numberings of products for "associate" use, for example, the 208A/101D, 209A/102D, and 210A/104D. Two tubes, identical electrically but with wholly different base styles, might or might not have the same number. Same-number pairs include the 201A-201B, 274A-274B, and 300A-300B; different-number pairs include 255B-266B, 267B-319A, and 315A-321A. The only attempt at distinctive numbering was the 700-series items, 700A through 730A, whose common characteristic was that they were developed for radar use between 1940 and about 1944.

WE-originated tubes made by Standard Telephones and Cables in Britain carried numbers like 4101D, 4102D, 4104D, 4215A, 4264A, and 4304CB, reflecting the U. S. prototypes less the "4."

"REPEATER BULBS" AND AUDIO TUBES OF THE TWENTIES

The classic tubes of early times have been well documented as to their physical characteristics; however, their applications are not as well known. Here are a few examples.

101D. Filament-type triode, replacing the 1923-vintage 101B in late 1921. "Tennis-ball" (2-3/8" dia, 4-1/4" high) bulb or ST (1-13/16" dia., 4-1/2" high) envelope, depending on whether made before about 1939; 4-pin base. Filament 4.2 V, 1.0 A. Transconductance, 1070 umhos. 25,000 hour life. Development code "L."

The 101D was perhaps the most interesting of the 101 family, which included A, B, D, F, FA, G, J, L, and M versions. One enthusiastic report [2] claimed it as "the oldest high-vacuum thermionic tube used in commercial communications (wired or radio) in the world," used more than 12 years as of 1926, "ever since its proportions were laid down by H. D. Arnold." It was "the type most widely used in the telephone plant" and "the most reliable and long-lived tube ever produced" as of the time. Some of its applications were as follows: as the oscillator and receiver tubes in the Type E power-line carrier system, ca. 1925; as the oscillator and balanced-modulator devices in the highly successful C4 three-channel open-wire carrier terminal, ca. 1928; in the D1 single-channel carrier telephone system; in the 22A1 telephone repeater, "probably the most widely used piece of vacuum tube apparatus used in the telephone plant" as of 1926 [3]; in the 2A and 2D gain-measuring sets; in the 4B, 6B, 6C, and 8A audio oscillators; in the 3A and 12A audio amplifiers; and in carrier telegraph terminals.

102D. Another filament-type tennis-ball triode, widely used in the Twenties. Filament 1.8 to 2.4 V at 1.0 A. G_m , 500 umhos. 25,000 hour life.

This item competed closely with the 101D for breadth of use. The 14B program amplifier, used on open-wire lines for network radio service, used a pair in push-pull, along with 104Ds as output stages. The 8B studio amplifier, intended to drive a disc cutter or a film sound recorder, employed a 102D feeding two 205Ds in tandem. The 17B amplifier, a two-stage version of the 8B, similarly used a 102D. The tube turned up as a rectifier in the 203C and 518A volume indicators, early predecessors of the volume-unit meter. The 44A1 four-wire telephone repeater used a pair, each as a voltage amplifier for a 101D.

104D. Filament-type power triode, replacing earlier versions as of 1922. "Tennis-ball" and ST styles. Filament 5.0-6.0 V, 0.97 A. G_m , 1180 umhos. Minimum life 10,000 hours; often 25,000. Development code "O."

This was a popular companion of the 101D, as in the transmitting and receiving group amplifiers of the C4 carrier system. These amplifiers used push-pull 101Ds feeding push-pull parallel 104Ds to obtain good linearity. (Negative feedback, with its performance enhancements, had not been invented yet.) A special six-channel version of C4 was used to multiplex the 1923 San Pedro-Catalina Island cable, which had replaced

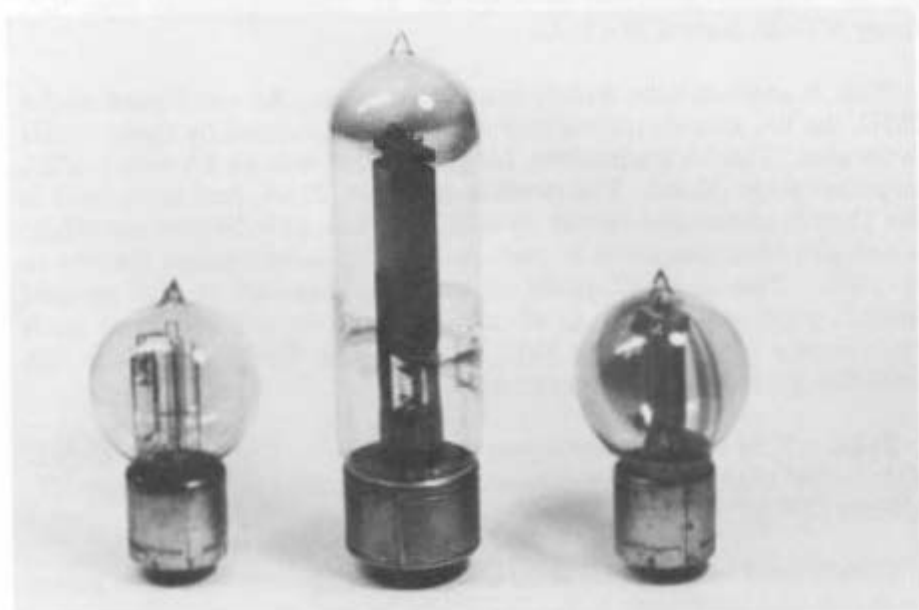


Fig. 2. Twenties favorites: 102D, 211A, 217A. Latter bears paper slip with "Licensed for use only as a part of the Western Electric loud speaking telephone outfit."

Photo: L. A. Sibley

the renowned AM-band radio link of 1922. As cited under 102D, the 104D served in network program amplifiers of the mid-Twenties.

205D. "Five-watt" filament power triode of tennis-ball style. Filament 4.0-5.0 V, 1.6 A. G_m , 1870 umhos. Development code "E."

The 205D is widely known because of its wide use in WE equipment sold to the non-telephone market. It appeared in the 8B, 8C, and 17B studio amplifiers. The 42A power amplifier used two for audio purposes, two more as rectifiers. The 6025B hexagonal-cased amplifier was similar, using one audio, one rectifier. The 32A public-address amplifier used the workings of a 6025B, with three 230Ds added as low-level stages. The 8A transmitter for aircraft [4] used 205Ds as oscillator and frequency doubler, feeding a 211D.

Because of this popularity, the 205D was available from outside sources like Jenkins and Adair of Chicago.

AIR-COOLED TRANSMITTING TUBES

Western Electric made low- and medium-power transmitting tubes from WW I until the product line was sold to Machlett about 1948. Some examples appear below.

211D. "50-watt" filament-type power triode. Filament power 10 V, 3.0 A. Typical operation at 750-1000 V. Developmental type "G"; Army VT-4B; Navy CW-1818A.

This is another tube widely used in its time. As mentioned under 205D, the 8A aircraft transmitter used one, modulated by three 211Ds in parallel. The 9A transmitter, for ground use, was an 8A with a 251A amplifier stage added. The predecessor tube, 211A, had been used in the Type E power-line carrier system, ca. 1926, as a 50-watt amplifier. It had also been employed in push-pull in high-power sound systems as of 1923. The D-77712 radio transmitter, installed at the original WEAf, used one as well, as an oscillator. A variant with wire leads instead of a plug base, the 211E, appeared in the 1929-vintage 10A amplifier for movie sound systems.

212A. "250-watt" filament-type power triode. Dimensions 13-5/8" high, 3-5/8" diameter. Development code "I," Army nomenclature VT-6, Navy CW-1819.

Widely used in broadcast transmitters, two of these served as power amplifier and modulator in the D-77712 transmitter.

251A. "1000-watt" filament-type triode. Dimensions 21-11/16" high, 6-1/8" diameter. Filament: 10 V at 16 A.

Developed about 1930, this device was intended for broadcast and shortwave transmitters. In AM ship-to-shore service, the transmitter on the liner *Leviathan* used a 251A modulated by a pair of 212Ds as of 1931 [5]. The WE 88-type 500-watt amplifier for police base-station service used a pair of 251As; the 9A transmitter for ground-to-air transmission employed this tube for 400 W output, and was also applied in a Florida-Bahamas telephone circuit.

The 251A reportedly introduced a number of features that were used for many years afterward: a molybdenum anode with fins and roughened surfaces for good heat transfer, a carbon-coated molybdenum grid, and hard (Nonex) glass for the envelope. It was also made by Amperex, but with a graphite plate. The 251A was developed into a 1200-watt tube of similar appearance, the 279A.

WATER-COOLED TRANSMITTING TUBES

For higher-powered transmitters, both in the broadcast market and in transoceanic/ship-to-shore radio, WE made a number of water-cooled transmitting triodes. Plate dissipation ratings were 5 kW (228A), 10 kW (220-type and 343A), 12 kW (240B), 20 kW (232B and 236A), 25 kW (340A and 342A), 100 kW (298-type), and 150 kW (320A).

320A. Filament power 35 volts, 435 A. Typical operation 15 kV at 8 A per tube. G_m , 31,000 umhos. Nominal frequency limit 2 MHz. Dimensions 94" high (about half of it glass), 12" diameter overall.

This remarkable tube of the late Thirties was intended for super-power AM transmitters, but the potential U. S. market disappeared in the wake of the FCC action denying WLW a license for 500-kW operation. However, a 500-kW Doherty-amplifier transmitter built by Continental Electronics for station XERA about 1940 used eight 320As [6]. This device was unusual in having three filaments, to operate from a three-phase supply.

GENERAL-PURPOSE ITEMS

WE made a wide line of low-power devices for audio and general-purpose use. Some typical examples follow.

215A. Filament-type audio triode, development code "N." Tiny for its time: 11/16" dia., 2-11/16" high. Filament rating 1.0 V at 0.25 A. Low-power design: typical output 3 mW. Army number VT-5; Navy designations CW-1344 and CW-38015.

The 215A "peanut" tube was developed in 1918 for portable military equipment but appeared too late for use in WW I. Four VT-5s did find

use in the Wireless Specialty Apparatus BC-144 receiver, ca. 1928. However, the 215A also was useful for civilian purposes. It appeared in Western Electric 500-kHz monitor receivers for broadcast stations (the 3A TRF model and the 4-type superhets). It was used in audiometers and, in the words of the time, "deaf sets." In Canada, Northern Electric used 215As in a consumer broadcast receiver. The 215A was applied in new equipment as late as 1930, in the crystal calibrator of the Navy TAV-1 portable HF communication station. While the 215A was nominally a low-frequency design, it could be made to oscillate at wavelengths as short as 1.9 meters.

This tube was featured in a group of TRF broadcast receivers specially built by WECO for the New York police ca. 1925. Every precinct house and "police booth" was to have a radio fixed-tuned to the city's station WNYC. Using railroad-type rotary selectors controlled by a 3000-Hz tone, a dispatcher would then be able to alert selectively any location, any group of sites, or the whole force. The receivers were made in AC and DC models, in black crackle cases [6].

262A. Cathode-type audio preamplifier triode, introduced ca. 1931. "S" bulb, 4-pin base, with grid cap; 4-3/4" high, 1-9/16" dia., similar to an old-style 24A. Heater 10 V, 0.32 A. G_m , 900 umhos.

This was a special development for use as in audio preamplifiers where low noise, especially low hum from the use of AC heater current, was essential. The intended field of use was public address systems, broadcast studio consoles ("speech input equipment"), and other high-quality sound systems, with an eye toward all-AC operation. The use of an unusually high heater voltage (for the time) at low current came from studies showing that hum arising from the heater came largely from the magnetic field, and hence would be least with a low current level. The 262A included a small, trapezoidal electrostatic shield visible over the heater wires at the base press. The use of a top cap for the grid was intended in large part to assure high leakage resistance between the heater and the grid (greater than 100 gigaohms), improving the hum level about 25 dB over contemporary single-ended triodes. The internal elements were braced for low microphonic noise. The 262A symbolized WE's dedication to competing with other audio makers on the basis of technical refinement; two years later, smaller suppliers like the Gates Radio and Supply Company were still introducing amplifiers using 27s and 37s as preamplifiers.

The 262A and 262B found their way into a variety of equipment, for example the 700A Volume Indicator, an early-Thirties precursor of the volume-unit meter; the 104B Amplifier; and the 86A Amplifier for theater sound systems. Perhaps the 262A's highest-profile use was in the BTL-sponsored demonstration of long-distance stereophonic music reproduction in April of 1933, when the Philadelphia Orchestra, playing

at the Academy of Music in Philadelphia, was presented to an audience in Constitution Hall in Washington. (The orchestra was led by Associate Conductor Smallens; the receiving equipment at the Washington end was controlled by the orchestra's regular conductor Leopold Stokowski – probably the world's most musically qualified remote operator.) The sound system was trinaural, with left, center, and right channels. The microphone preamps at Philadelphia were 80A amplifiers using 262As; the receiving line amplifiers at Washington also used 262As [8].

310A. Cathode-type high-frequency pentode, introduced ca. 1936. ST bulb, 6-pin base, with grid cap. Heater 10 V, 0.32 A. G_m , 1800 umhos. Second-sourced by Raytheon.

This design is like a slightly elongated 6C6, but with silver-plated base pins. The heater ratings were chosen with the intent of using the heaters of two 310As in parallel, the combination being wired in series with a 311A on a 24-volt regulated battery supply.

The 310A's original use was in the line amplifiers of the K1 carrier telephone system. K1 was the first cable-carrier facility, a 1936-vintage design that delivered 12 voice circuits via a 19-gauge cable pair in each direction. After a field trial between Detroit and South Bend, it was installed widely until the improved K2 design became available in the early 1940s. Thus the "K" systems that connected New York and San Francisco beginning in 1942 used a mix of K1 and K2 lines. The 310A was used in the first two stages of the line amplifier, a repeater placed at intervals of about 17 miles along the cable, typically in distinctive square brick huts with gabled roofs.

The 310A was broadly useful in other audio and high-frequency applications over the next 25 years: in the high-frequency portions of the Type J 12-channel open-wire carrier system, ca. 1939; in the 14C program amplifier, a unit of 15-kHz quality that was widely used on network radio circuits up into the solid-state era; in the V1 telephone repeater, ca. 1940; as a DC amplifier in the power supply of the TJ microwave radio system, ca. 1960; as the audio amplifier in the "Mickey Mouse" transmission measuring system, an ingenious level-measuring set that projected meter readings onto a screen about two by four feet so that it could be read from anywhere in the room; and so on.

The 310B was a development, modified slightly to give reduced noise with AC operation of the heater.

311A. This pentode, a 5-pin design with grid cap, was physically similar to the 310A and was its power-amplifier companion in the K1 line amplifier, 14C program amplifier, J-carrier repeater, transmission measuring set, etc. Heater operation used 10 V at 0.32 A.

328A. This tube was a 7.5-volt version of the 310A, for the same uses but intended for use in telephone offices where the battery supply was not closely regulated at 24 volts. In this case, two 328As with heaters in parallel were wired in series with a 329A, taking a total of 15 volts. The difference from the battery voltage was made up in a ballast lamp. This application was not common.

A pair of 328As were used, along with a 274A as rectifier, in the AC-powered version of a repeater for the H1 carrier telephone system, which derived a second voice path from an open-wire pair. H1 was quite popular with railroad telephone systems in the Forties and Fifties.

329A The 329A was the 7.5-volt twin of the 311A; see 328A for its field of use.

348A. A check of ratings and physical details shows this pentode to be a 310B on an octal base, with octal-size grid cap, and with a 6.3-V, 0.5-A heater. It was used as a low-noise preamplifier in studio audio equipment, for example the 40A console, 120C and 121A line amplifiers, 124-type monitor amplifiers, 129A quadruple preamplifier, and other main elements of WE's postwar broadcast line.

382A. Heater-type audio triode. Six-volt heater. No-base construction, to be wired into the circuit.

The 382A was the small (1-1/2" high, 1-3/8" diameter) preamplifier tube in the RA-1095 amplifier for the 640AA capacitor microphone [10]. The size of the housing (to go at the end of a microphone boom) forced use of a relatively tiny leadless tube. The 387A pentode was similar, but with a separate plate lead.

"DOORKNOB" UHF TUBES

The no-base, minimum-size "doorknob" tubes developed between about 1933 and 1937 were a successful attempt to provide devices useful in the then-new VHF-UHF spectrum.

316A. Filament-type transmitting triode, 2-11/16" dia., 2-25/32" high. Filament rating 2.0V at 3.65 A. Dissipation rating 30 W. Army type VT-191. Second-sourced by GE and Tung-Sol.

The 316A was developed about 1934, apparently from an experimental device coded 149Y having very similar ratings. It was a power tube capable of operating at UHF with appreciable CW power output: 8.5 W at 300 MHz, 4 W at 600 MHz, and an upper limit of oscillation of 700 MHz. It achieved a 30-W dissipation rating despite having a plate

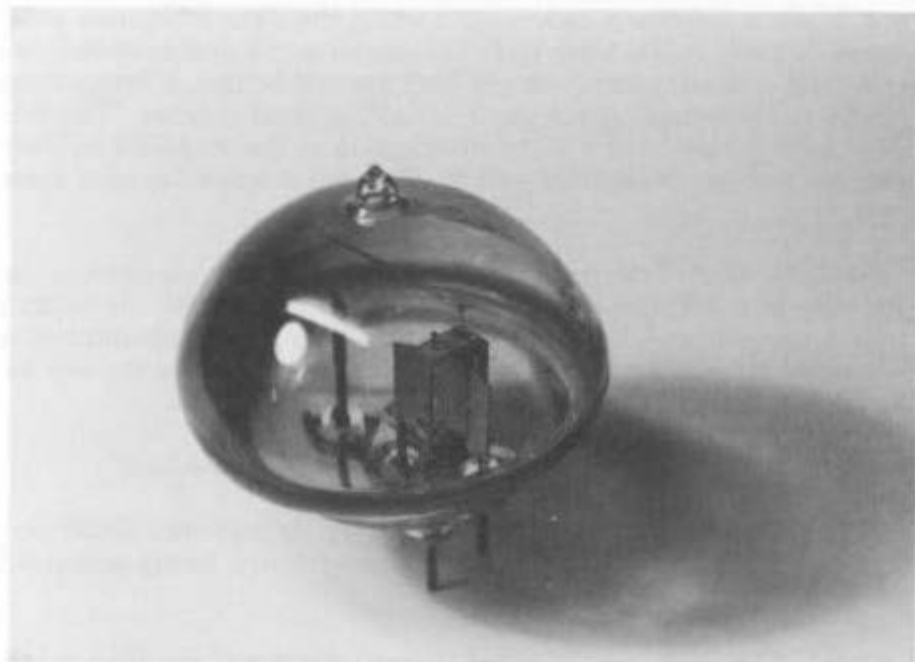


Fig. 3. 316A/VT-191 doorknob triode, GE production.

Photo: L. A. Sibley

only about 1/8" in diameter. Its construction introduced the use of a molded-glass "dish" stem.

It was convenient "off-the-shelf" technology for a number of UHF applications just before WW II, and thus became the best known of the "doorknob" family. The 316A found its way into the following uses: as the 700-MHz local oscillator in the Mark 3 radar; as the receiver *preamplifier* in the Mark 3 and 4 radars, until GE's 446-type "lighthouse" tubes became available; in the GE RT-1248 transceiver and, perhaps the most familiar of all applications, as the transmitter tube in the BC-645 and ABA airborne identification-friend-or-foe (IFF) sets. In this latter use, it generated 20-W pulses in the 435-500 MHz region.

368A. Another doorknob design, the 368A could dissipate 20 W and deliver 3 W at 1250 MHz. It was tried as the receiver input tube in radars ca. 1940, being one of the few devices available that could work at 800 MHz, although with the rather poor noise figure of 23 dB. It served in pairs as the transmitter tubes in the Navy's pioneering CXAS

and Mark 1 shipboard radars, generating the then-substantial peak power of 2 kW at 700 MHz [11]. Developed into a double-ended version (with grid and plate leads out both top and bottom, it became the 368AS and was employed in the T-26/APT-2 radar jammer. The WE 703 seems to have been a slight modification of the 368AS for military use, and was interchangeable with it. Tung-Sol produced at least some 703s.

D156548. One of the smaller doorknob UHF tubes, this one was the RF tube in a WE radar altimeter developed about 1937. It worked with a companion UHF diode coded D157653. The altimeter was somewhat large and power-hungry for wide use, but paved the way for RCA's highly successful AN/APN-1 that used acorn tubes.

HIGH-FREQUENCY AMPLIFIERS – 386 FAMILY

High-performance pentodes were necessary for improved circuit performance in the late Thirties. The following design family addressed the problem.

384A. The 384A was the power-stage companion of the 386A in line amplifiers of the L1 system; see below. It had the same physical design. Rated at 200 mW output. With an octal base and plate cap added, this item became the 385A.

386A. Cathode-type pentode, developed in 1939. Special bulb without base, to be wired into the circuit; plate lead through top. Heater 6.3 V at 0.15 A. G_m 4000 umhos.

This small pentode was developed for use in the remote line amplifiers of the L1 carrier system. L1 was the first commercial coaxial transmission system, using a coaxial tube in each direction to pass 480 voice circuits in the 60-2088 kHz range (later, 600 circuits). First applied in 1940 on a cable between Stevens Point, Wisconsin, and Milwaukee, it was installed fairly widely until the L3 system became available in the mid-Fifties. (The Stevens Point cable remained in service as late as 1980. Circuits from Minneapolis went on into Milwaukee via Type K wire-pair carrier facilities.) L1 could carry a television channel in place of the voice circuits, and was used this way for network transmission until TDX and TD-2 microwave facilities became available in the late Forties.

Line amplifiers for L1 were placed in huts about eight miles apart, and were powered by sending high-voltage AC through the coaxial cable from terminal stations. The three stages of each line amp employed a pair of tubes in parallel in the interests of added reliability. The 386A was a voltage amplifier in the first two stages, driving a 384A output stage. The tubes were non-based to minimize stray capacitance and inductance. The 386A turned out to be important far beyond the

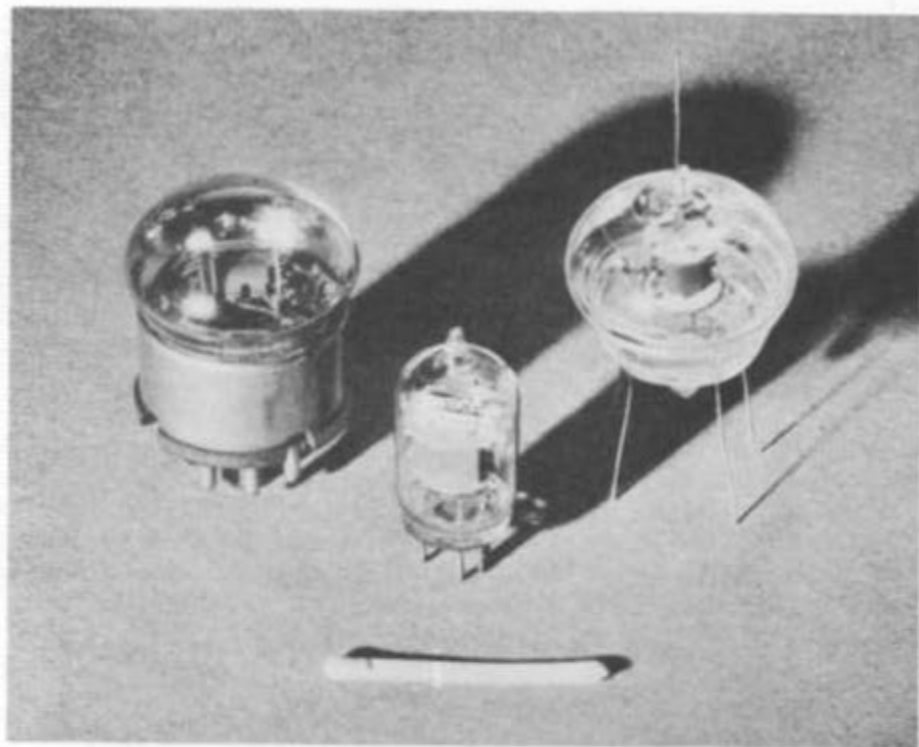


Fig. 4. The 717A, 403A/6AK5, and 386A pentodes.

Photo: Reprinted with permission from the Bell Laboratories Record, 1944 AT&T.

L1 system: it was the beginning of the 717A, 6AJ5, and 6AK5; as described below.

717A. Cathode-type high-frequency voltage amplifier. Special short "mushroom" bulb on octal base. G_m 4000 umhos. Army designation VT-269. A variant of the 717A with slightly different parameters was the 713A.

The 717A was a wartime development of the 386A pentode, with the mount turned on its side and the plate lead brought out through the base. It was used in early radar IF amplifiers at 30 and 60 MHz, as an alternative to the 6AC7, and was replaced in turn by the 6AK5. Typical sets using the 717A were the AN/APQ-7 and -13 3-cm bombing radars used widely in B-29s, the Philco AN/APS-15, and the SCR-717 airborne search set. The 717A also figured in the RF sections of the BC-733 localizer receiver and the R-28/ARC-5 VHF command receiver.

This tube was one of the few Bell Laboratories-designed tubes, other than the 6AK5, to find its way into consumer electronic equipment,

having been used in a 1946-vintage FM converter produced by the E. H. Scott Radio Laboratories [12]. The converter, a three-717A design, adapted tuners intended for the prewar 42-50 MHz FM band to 88-108 MHz reception. (Considering the tiny production quantity, the 717As may well have been military surplus.)

403A/6AK5. A natural development of the 717A design was to put it in a seven-pin miniature envelope. The result was the 6AK5, widely used in radar IF amplifiers after about 1943. Further development led to the 6AJ5, optimized for use with 28-volt plate supplies in aircraft equipment. With multiple makers, the 6AK5 was widely used in consumer electronics in the late Forties.

408A/6028. Conversion of the 403A to operation with a 20-volt 50-mA heater (for use on telephone battery supplies) gave the 408A. This design appeared in a wide range of equipment of the early Fifties: in the V3 telephone repeater, the channel units of the 43A1 17-channel carrier telegraph system, 1600-Hz signaling sets, and channel circuits of the N1 12-channel carrier telephone system.

KLYSTRONS

Like Sperry, Bell Labs and WE played an important role in developing the klystron from an invention to a mass-produced radar component. Table 2 lists a variety of Western klystrons. It covers the external-cavity types, the 723-style items, a pair of electrically/thermally tunable items for frequency-agile radars, and a number of 1959-1965 vintage designs that were used in Bell System microwave systems. The application of the 452A and 449A is of interest: in order to obtain an unusually linear FM modulator with 70-MHz output, it was decided to use a pair of microwave klystrons operating 70 MHz apart, frequency-modulate one of them, and take the difference frequency.

723A. Metal reflex klystron with integral cavity, tunable from 8702 to 9548 MHz. Octal base with small coaxial output line replacing pin 4; repeller lead on top cap. Heater rating 6.3 V at 0.44 A. Output power 33 mW with 300 V supply. Also produced by (at least) Raytheon and Ken-Rad.

The 723-type klystrons were developed as packaged local oscillators for 3-cm radars [13]. The earlier 707-type klystron, with its external clamp-on cavity, had proven troublesome due to corrosion troubles in humid climates. An integral-cavity sealed design was highly preferable. The 723A and its successors the 723AB and 2K25 found use in generations of equipment: the WE AN/APS-4, Philco AN/APQ-7, and WECO AN/APS-15; the receiver in the Bat radar-guided glide bomb, the Hewlett-Packard "Type G" 9700-MHz signal generator, etc.

TABLE 2 WESTERN ELECTRIC KLYSTRONS

Type	Freq. (MHz)	mW Out	Year	Typical Use	Other Makers	Remarks
EXTERNAL-CAVITY TYPES IN DISK-SEAL FORMAT						
402A	3700-4200	500	1947	TDX Trial		Dual-cavity
707B	1150-3750	140	1942	SO Radar, AN/APN-7	Ray, H&K	Octal base
INTERNAL-CAVITY TYPES IN 723-STYLE OCTAL FORMAT						
397A	3840-4460	90			RCA	
452A	3900-4460		1950	TD-2 Terminal		Used in pairs
723A	8700-9550	20	1943	AN/APS-4 @	Ray	
726A	3150-3400		1943			
B	2800-3200		1943			
C	2700-2900		1943			
2K22	4200-4900	100	1944	AN/TRC-6 Rcvr		
2K23	4280-4880	400	1944	AN/TRC-6 Xmtr		
2K25	8500-9700	20	1945	AN/APS-4 @	Ray #	Repl. 723A
2K26	6100-6900	120			RCA †	
2K29	3350-3950	120				
2K54	4290-4560	900	1944	AN/TRC-6 Xmtr		Repl. 2K23
2K55	4590-4860	900	1944	AN/TRC-6 Xmtr		Repl. 2K23
2K56	3800-4400					
INTERNAL-CAVITY THERMALLY-TUNED TYPES WITH OCTAL BASES						
2K45	8500-9700	20	1944	Tunable Radars		Half-6L6 case
2K50	23.5-24.5*	20	1945	Tunable Radars	H & K	Half-6L6 case; waveguide out
INTERNAL-CAVITY TYPES WITH WAVEGUIDE OUTPUT (BELL SYSTEM USE)						
445A	10.7-11.2*500		1959	TJ Xmtr & Rcvr		
449A	5850-6500	12	1960	Sweeper for TH1		
450A	6000-6200		1960	TH1 Terminal		Used in pairs
457A	10.7-11.2*100		1961	TL Xmtr & Rcvr		Octal powering
459A	5900-6500	100	1965	TM Transmitter		
459B	5900-6500	<90	1965	TM Receiver		

* GHz.

@ Also AN/APQ-7, AN/APQ-13, AN/APS-15, AN/APS-31, etc.

% Also Raytheon and Amperex

Also Amperex, Ken-Rad, and Heintz & Kaufman.

The three radars listed actually used a pair of local oscillators, switchable, for normal and beacon operation on different frequencies. The physical design of the 723-type formed the basis of similar reflex klystrons operating at much different frequencies like the 397A (3840-4460 MHz), the 2K26 (6250-7060 MHz), and the 2K29 (3350-3950 MHz). The 723 was a favorite RF source for laboratory microwave demonstrations. It could be tuned into the 10-GHz amateur band, with the proviso that the user not touch the shell of the tube, which operated 300 V above ground.

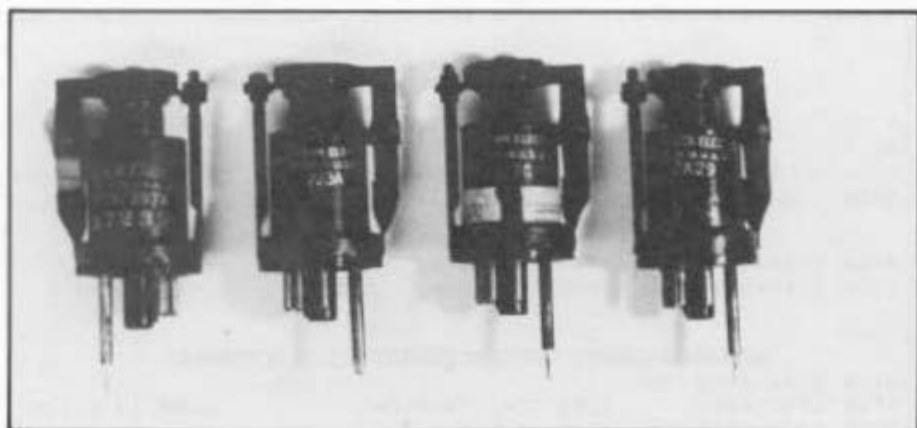


Fig. 5. Klystrons: 2K56/397A, 723A, 726C (preproduction model), 2K29. Common package design, but frequencies range widely, from 3.35 GHz (2K29) to 9.55 GHz (723A). *Photo: L. A. Sibley*

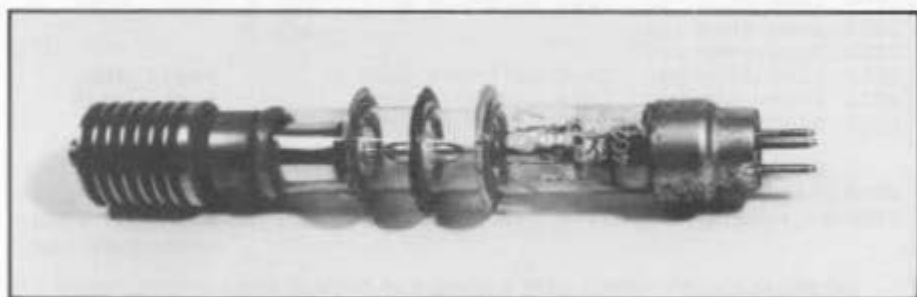


Fig. 6. 402A klystron.

Photo: L. A. Sibley

While a landmark, the 723-type was not the first metal klystron. A very early GE unit, devised almost simultaneously with the Varian brothers' work that lead to their klystron patent, looked like a 6F6 tube with a coaxial line coming out one side and a repeller lead emerging from the top. The same GE development yielded a six-cavity design in a metal octal shell about ten inches long.

402A. External-cavity amplifier klystron for the 3700-4200 MHz range. This device, involving two clamp-on cavities, was an early approach to the problem of an amplifier for microwave radio systems. It made its appearance in the "TDX" experimental radio-relay system between New York and Boston in 1947 [14]. Each of the eight radio sites on the route used a transmitting amplifier comprising four 402As connected in tandem. Together, they consumed about 180 watts of heater and B+ power to give about half a watt of RF output. However, they demonstrated that microwave systems could be built to handle several hundred telephone channels or a high-quality television picture. The TDX experiment, after sizable redesign, led to the TD-2 radio system

TABLE 3 WESTERN ELECTRIC MAGNETRONS

Type	Freq. (MHz)	kW	Remarks
COAXIAL-OUTPUT TUBES, 3400 MHz AND BELOW, WITH EXTERNAL MAGNETS			
700A-D	680-720 F	40	Mk. I radar refit; Mk. 3, Mk. 4.
706A-C	3019-3100 F	25	Early ship & air radars; multi-mfgr.
706AY-GY	2914-3100 F	150	
714A	3280-3320 F	22	Early ship & air radars.
714AY	3280-3320 F	125	
718AY-EY	2720-2890 F	136	Dev. from 706A-C; 2000 hr. life.
720A-E	2720-2890 F	1000	Double-length version of 718AY-EY.
728A-J	900-970 F	275	In fire-control & search radars, replacing systems using 700-type.
4J21-30	1220-1350 F	600	Replacement for 5J23; spark pulser.
4J42	660-730 T	40	Tunable replacement for 700A-D.
4J45-47	2750-2855 F	1100	Long-pulse version of 720B-D.
4J51	900-970 T	285	Tunable replacement for 728-type.
5J23	1074-1086 F	450	Pack sets & searchlight control.
5J26	1220-1350 T	600	Tunable replacement for 4J21-30.
WAVEGUIDE-OUTPUT TUBES, >3400 MHz, INTERNAL MAGNETS UNLESS NOTED			
725A	9375 F	55	Interchangeable with 2J21. # &
730A*			In SCR-717 & AN/APQ-13.
2J48-50	9315, 9080, & 8825 F	50	Based on 725A. # &
2J51	8500-9600 T	55	Based on 725A; tunable & packaged.
2J53	9375 F	225	Replaced early by 4J50 & 4J52. &
2J55-56	9375 & 9245 F	50	Derived from 2J51.
3J21	24,000 F	60	
4J50	9375 F	280	
4J52	9375 F	100	Similar to 4J50.
4J78	9080 F	280	Similar to 4J50.

F: fixed-frequency; T: tunable

* See 725A - different mechanical details.

@ 2J48 operates at different frequency, with closer frequency tolerances. 2J49 and 2J50 were produced by others.

Used in Philco AN/APQ-15. WE, Northern Electric, and Raytheon made 300,000 of these.

% External magnet (non-packaged design)

and transcontinental microwave service by 1951. By then, it was possible to use 416-type triodes as the transmitting amplifier.

The 402A had a small place in the TD-2 system, as a sweeping oscillator in a signal generator, part of a test bay used in lining-up the equipment.

MAGNETRONS

Small, low-power magnetrons used with external tuned circuits were widely known during the Thirties. They would oscillate well into the UHF region. However, they could not produce the power output needed to build microwave radars. All that changed when the British

devised the cavity magnetron at the start of WW II. Under U. S. - British cooperative agreements, a sample magnetron was flown to the U. S. in great secrecy in late 1940. It became the prototype for the 700A and about 75 other magnetron types [15] eventually made by WE, as well as by Sperry, Raytheon, and others. Table 3 lists WE magnetrons and their uses. The devices were divided design-wise as fixed-frequency or tunable, as external- or internal-magnet (packaged) types, and as using coaxial or waveguide outputs. These were almost entirely a wartime enterprise for Western, apart from some military work lasting into the Fifties.

700A. This device was a fixed-tuned 700-MHz unit capable of 40 kW pulses. Its output was via a coaxial line. Used in such shipboard gun-laying radars as the improved Mark 1, Mark 3, and Mark 4, it was in operational use by 1942. A feverish development program soon obsoleted it, but the 700A was the first of its kind.

TRAVELING-WAVE TUBES

WE made a small but important line of TWTs for military and Bell applications. These included the 444A described below, the 461A in the 4000-MHz TD-3 microwave system, the 462A for the TM-A1 microwave amplifier, the 473A ultra-linear type for the AR-6A 6000-MHz single-sideband microwave system, the 6784 low-noise 3000-MHz type for military use, and the M4041 3.5-watt space-qualified unit for the 1962 Telstar satellite experiment.

444A. This tube was used in the microwave carrier supply and transmitting amplifier of the TH-1 microwave system, introduced ca. 1960. Developed from a prototype coded M1789, it produced five to seven watts at 6000 MHz over a lifetime of three to five years. It was used with a permanent focusing magnet, and was air-cooled.

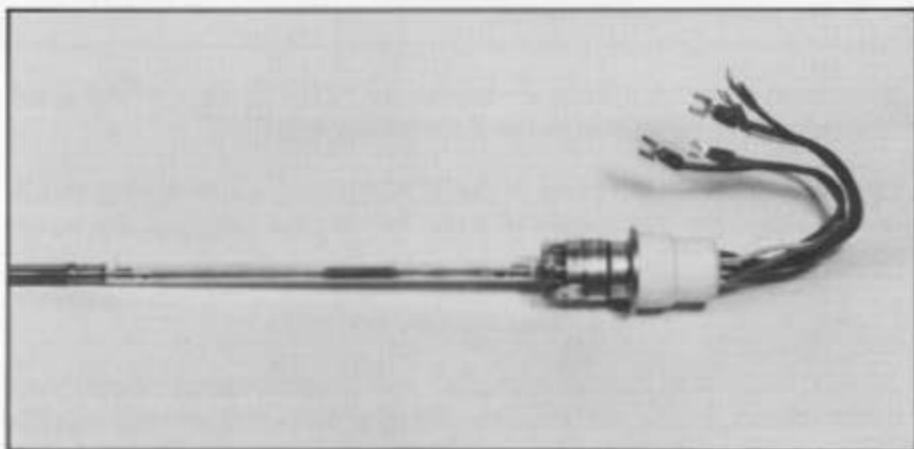


Fig. 7. 444A traveling-wave tube.

Photo: L. A. Sibley

CATHODE-RAY TUBES

The WE line of the 1920s and 1930s included a small number of oscilloscope tubes. These were the 224-type, which used argon gas under very low pressure for focusing; the 302A, the 325-type (4-1/4"), 326-type (7"), and the triple-beam 330-type (7"). The latter three used a novel two-base design for their leads: a conventional pin base at the base of the neck, and a molded ring around the neck, part way up, with pins for the deflection plates. This design avoided the use of four fragile caps as was done on conventional tubes like the 905 or 914. The tubes were offered in A, B, and C versions having different phosphors.

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Reference sources for this article were several: the "Bell System Technical Journal," the "Bell Laboratories Record," and the "Proceedings of the Institute of Radio Engineers" over the time span from 1925 to 1955 provide numerous application examples for WE tubes. Three volumes of the series A History of Science and Engineering in the Bell System, specifically The Early Years (1875-1925), National Service in War and Peace (1925-1975), and Electronic Technology (1925-1975), contain valuable resumes of the development of Western tubes. "Electronics" in the late Thirties contained informative monthly full-page advertisements, and immediately after WW II provided additional detail on wartime devices and systems like radars. The Radio Division of WE published comprehensive listings of tube characteristics, for example the 1946 catalog of devices available for general sale through the Graybar Electric Company. Specific references are given for major items; however, in some cases the information on application of a particular tube has come from such diverse sources as inspection of an antique amplifier.

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