

# SECRET TUBES FOR RADAR: THE WESTERN ELECTRIC 700-SERIES

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## INTRODUCTION

Bell Telephone Laboratories coded the 700-series of tubes (700A through 732A) for military applications during WW II. These types were intended for production by Western Electric, Northern Electric, and a wide variety of other contractors. Developed on a "crash" basis under pressure of the war situation, these designs were used mainly in radars, with some further applications in communications gear. Many were advanced technology, yet only a few lasted beyond the war. Some are well documented; others, developed for special applications or obsoleted early, are quite obscure, not listed in available catalogs or data sheets. A few were simply adaptations of British tubes for North American manufacture, but most were original designs. All are collectable examples today.

Development of the 700-series ran from early 1941 to mid-1943, when assignment of new codes shifted to Radio Manufacturers' Association (RMA) numbering plans: either the existing scheme for "receiving" tubes or the then-new code for special-purpose types. In particular, the 6AK5 and 3B24 were registered with the RMA in April 1943, and their corresponding designations 731A and 732A were dropped. Later in the same month the 703A, 704A, 705A, 713A, and 717A were registered, the only other 700-series types to be so treated during the war.

The most popular designs were widely manufactured by other makers, to such an extent that production by Amperex, Ken-Rad, Northern Electric, Raytheon, Sylvania, Tung-Sol, STC and other British producers, etc., doubtless exceeded that of Western Electric itself. Certain of these BTL-designed items may have been made entirely by makers other than WECO.

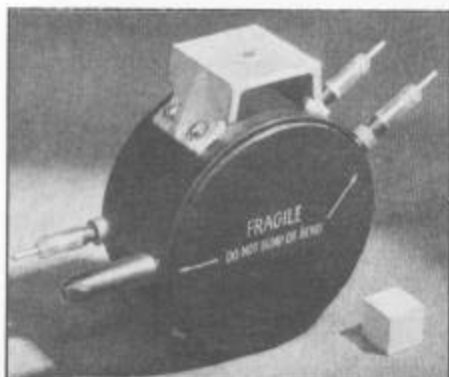
These tubes were remarkably diverse. They generated power levels from milliwatts to a megawatt, operated at frequencies from 60 Hz to 9550 MHz, and represented nearly the entire known spectrum of tube constructions.

This article does not attempt to go into the important contributions to radar-tube technology by such makers as GE, Raytheon, Sperry, or Westinghouse; or by organizations like the MIT Radiation Laboratory. Nor does it deal with the many Western Electric radar tubes that were developed from the 700-series. The original tubes in this line are quite enough to cover!

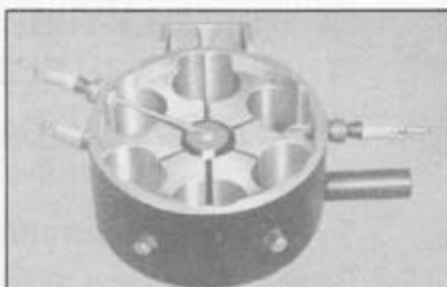
## SOME RADAR TERMS

Before going into detail, it may be helpful to define some types of tube that are unfamiliar to many tube historian-collectors because of their specialized nature.

**Klystron.** In the 700-series, these are small microwave oscillators, generating a few dozen milliwatts of power, made mainly for local oscillators in radar receivers. Klystron amplifiers, power tubes, etc. came later. More particularly, these are *reflex* klystrons in which only a single resonant cavity is needed -- a "repeller" electrode causes the bunches of electrons that give rise to oscillation to



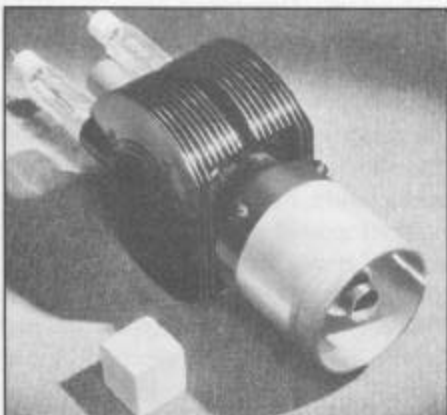
The 700A 700-MHz magnetron.



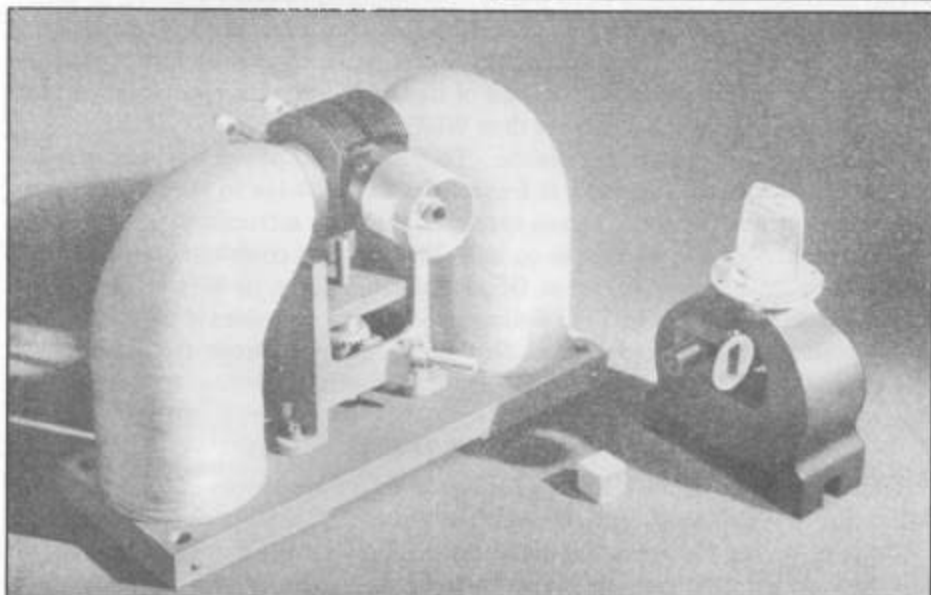
The 700A with its cavities.



The 706Y. The cube is 1" square.



720A, with coaxial output line.



720-type and 725A magnetrons in their magnets.

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sweep past the cavity multiple times [1]. Since the name "klystron" was a trademark of the Sperry Gyroscope Company until well after the war, contemporary BTL and WEC literature refers to these tubes as "reflex oscillators."

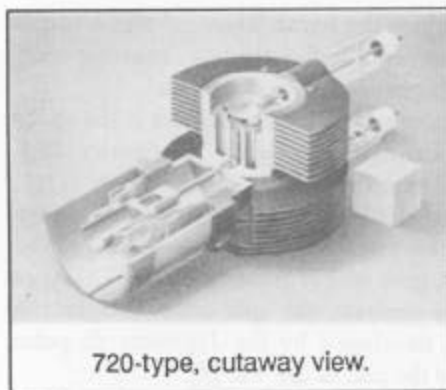
**Magnetron.** Again for purposes of this series of tubes, the subject is the cavity magnetron, or, more specifically, the multicavity magnetron. The cavity magnetron was a 1940 British discovery, shared with the U. S. in great secrecy in late 1940. It made far greater power levels possible, a requirement for microwave radars whose short wavelength gave precise resolution of the target [2]. The 700A, WEC's first production magnetron, gave 40-kW pulses, and the 720-types produced 1000 kW shortly afterward. By contrast, the split-anode magnetron was well known internationally, and was developed by the Japanese to pulse power levels of several kilowatts at 3 cm by the end of the war [3].

Magnetrons in the 700-series were early design-wise: they were fixed-tuned by the dimensions of their resonant cavities, a disadvantage if faced with an enemy capable of jamming the radar. This also required multiple spare units where several radars of the same type, each assigned to a slightly different frequency, were on a given ship. The early devices were all of the external-magnet type, wherein a bulky fixed magnet supplied the magnetic field required for operation. Later designs in the 2Jxx- and 4Jxx-series, ca. 1943, were "packaged" types incorporating integral magnets for lesser bulk and weight, a design practice continued to the present. However, lest these early devices be considered failures, it should be noted that some served until well after the war.

**TR Tube/ATR Tube.** This is a small gas-discharge tube which provides electronic switching of a single antenna between transmit and receive functions at rates up to 1000 or 2000 times per second. Strategically placed in a resonant cavity coupled to a waveguide, it "breaks down" (fires) and short-circuits the waveguide, protecting the mixer crystal in the receiver from the transmitted power. A second tube, the anti-TR or ATR tube, effectively disconnects the transmitter from the antenna feedline during receive time, keeping the weak received power from being lost in the transmitter. In these tubes, a third electrode is usually present, carrying a small DC current to keep the gas in the tube lightly ionized, assuring fast response when the transmitter is pulsed "on." A typical TR system of WW II vintage would allow, of 200 MW of transmitter power, only about 200 mW to reach the receiver -- an isolation of 90 decibels.

**Modulator.** This is a power tube, a switch which applies power to the magnetron in brief pulses: for example, 12 amperes at 20 kV for one microsecond, 1000 times per second. This requires the ability to handle unusually high voltages (often at high altitudes where insulation and cooling are difficult) and moderately high power dissipation. The 700-series modulator tubes were air-cooled tetrodes of the top-cap type. These "hard" tubes competed with thyatrons, rotary spark-gap devices (comparable to the rotary gaps of "wireless" days) and sealed spark-gap tubes.

**Frequency, Band, and Wavelength.** In dealing with radars, there is room for confusion in terms of the part of the radio spectrum in which they operate. RF-generating tubes in the 700-series operated in, generally, five frequency bands. The lettered band designators began as a wartime security measure to disguise operating parameters of radars, but were kept afterward for convenience. (The bands are lettered somewhat differently today.)



720-type, cutaway view.



725A, with waveguide output.



728-type, with glass shield on fragile heater leads.



730A, in-line version of 725A.



A 707A with its tunable cavity.



723A and 726A klystrons. 726A has slightly thicker output line; also simpler repeller support.

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| Frequency | Wavelength | Band | Example           |
|-----------|------------|------|-------------------|
| 175 MHz   | 170 cm     | -    | 710A              |
| 700       | 40         | L    | 700A, 702A, 703A  |
| 1000      | 30         | L    | 728A              |
| 3000      | 10         | S    | 706A, 707A, 726A  |
| 10,000    | 3          | X    | 723AB, 725A, 730A |

### INTERNATIONAL "TECHNOLOGY TRANSFER" IN RADAR

Radar technology in WW II was a state secret for the warring powers. All entered the war with some form of radar [4]. Britain had the Chain Home defensive screen, early antiaircraft gun-directing sets, and naval systems. Germany had long-range aircraft detector radar (the 125-MHz Freya system), the Wurtzburg 600-MHz air-defense system, the Seetakt 375-MHz naval radar, and others. France had working aircraft detectors and harbor-defense systems. Philips in the Netherlands had devised a basic 400-MHz radar set, actually used in combat in 1940, which was evacuated to Britain to keep it out of German hands. The Italian Navy possessed a few shipboard radars. Japan had simple VHF aircraft-detection and naval search sets, which grew to 52 Army designs and 62 Navy versions by the end of the war. The Soviet Union had built basic VHF aircraft-locator systems. The U. S. had land-based aircraft-detection radars (the 105-MHz SCR-270 and -271), air-defense sets (the 200-MHz SCR-268), and naval search and air-defense sets. Even the Hungarians had developed operational systems (which culminated in their obtaining radar echoes from the moon in 1946). Thus radar was hardly unique to any of the combatants. Because of the secrecy aspect, these systems were locally developed.

As the war progressed, nations friendly with each other shared radar technology: lavishly, in the case of the British, the Commonwealth, and the U. S. We received the magnetron and the silicon-crystal mixer from the British, as well as the designs for early VHF air-to-air and air-to-surface-vessel (ASV) radars. In turn, the British obtained mass production of complete systems, plus supplies of tubes and other parts, which explains why most of the 700-series tubes carried British Common Valve (CV) numbers. The U. S. supplied the Soviet Union with radars of advanced design under the Lend-Lease program. The Germans provided the Japanese with the critical parts of a Wurtzburg radar and manufacturing information, shipped by submarine in early 1944 [5]. (The Japanese were slow to adapt the design to their parts designs, and failed to get the set into production before the end of the war.)

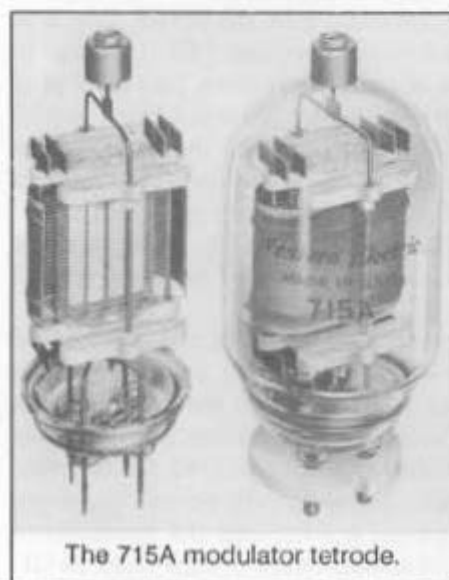
The security problem with radar was severe: with each side making technical advances (mainly the Allies, who, on the defensive early on, poured resources into development), the need to keep those advances out of the enemy's hands was critical. There was a fair amount of unintended technology transfer as the result of equipment capture. In the evacuation of France in 1940, the Germans seized a British 200-MHz radar at Boulogne, but apparently weren't impressed with it [6]. In capturing Singapore, the Japanese got drawings and specifications for British sets of the same design, and built similar radars of their own. In taking over the Philippines, they harvested a working SCR-268 on Corregidor and got enough partially destroyed SCR-270s to assemble working sets for evaluation



The 701A modulator tetrode.



707A reflex klystron.



The 715A modulator tetrode.



Near-twins: 713A and 717A.

*Photos of 701A, 707A, 715A copyright (c) 1946 and 1947 AT&T. Reprinted with permission.*

[7]. Their Type S-3 was a close copy of the SCR-268. In investing Guadalcanal and Kiska, the U. S. obtained working Japanese radars; one of them spent the war under test, looking out over Chesapeake Bay. The British raided the German antiaircraft site at Bruneval on the French coast, sweeping up the most critical parts of a Wurtzburg (and a frightened operator). They got the 400-MHz Liechtenstein air-to-air radar from a JU-88 night fighter that landed by mistake in England. Much of each side's interest in the other's radars was not in duplicating the equipment, but in finding its weak spots to build more effective jammers.

Perhaps the most critical transfer was the loss of the cavity magnetron to Germany. An RAF Stirling bomber equipped with the "H<sub>2</sub>S" navigation/bombing radar crashed in the Netherlands in early 1943. From it German technical-intelligence specialists extracted the mangled radar and its CV64 10-cm magnetron, and advised their Japanese allies via a long radiotelegram. This was the "Rotterdam geraet" (apparatus), the focus of intense effort that eventually yielded a working replica. The German copy of the CV64 magnetron was the LMS 10(G) [8].

The Western Electric 700-series tubes were sensitive technology at the time -- the data sheets for at least six of them were classified information. They figured in this accidental transfer to some extent. A year after the British inadvertently revealed 10-cm technology to the Axis, a B-17 carrying an "H<sub>2</sub>X" bombing radar (AN/APQ-13 or AN/APS-15, X-band versions of the H<sub>2</sub>S) was shot down in Holland. This revealed 3-cm radar designs: the 725A/730A magnetron, 723AB klystron, etc. The Japanese, too, recovered APQ-13s from shot-down B-29s. They made rapid progress in developing cavity magnetrons. However, these losses came too late in the war to have a real effect.

### MILITARY EFFECTS OF RADAR

The effect of radar on warfare is a topic occupying entire books. As one example, the Imperial Japanese Navy had developed, during the Thirties, high skill in surface combat at night. They put this advantage to work in, for example, the First Battle of Savo Island in the Solomons on August 9, 1942. The result was a "the worst sea defeat in its entire history" for the U. S. Navy [9]: three U. S. cruisers, and one Australian, sunk. Radar, properly applied, would be an equalizer to reduce the Japanese advantage. In the Battle of Cape Esperance (Second Battle of Savo Island), about midnight of October 12-13, the Mk 3 and Mk 4 radars (see 700-type below) were used in giving the Japanese their "first defeat ever in a night action" [10], with the loss of a cruiser and a destroyer, at the cost of an American destroyer. (Japanese losses were exaggerated by a factor of three at the time [11], but such is the nature of wartime reporting.)

In terms of air warfare, radar brought similar changes. Not too far into the war it became possible for an air force to bomb an enemy city fairly accurately through clouds, and for the defenders to direct rather accurate antiaircraft fire up through the same clouds.

### TECHNICAL DETAILS

**Multiple numbering.** Most of these tubes carried multiple numbers assigned by the military services, the RMA, and the various makers. The most extreme



702A and 709A TR tubes.

The 709A with its associated cavity.



The 721A, 1B23 (729A), and 724A TR tubes.



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case is the 710A, which was known by at least nine designations. Table 1, derived from American and British sources [12, 13], lists the multiple numbers for the more complex cases.

**Production life.** Many of these tubes were quick-shot designs, destined to be replaced quickly by more advanced types. Yet the "Army-Navy Preferred List of Electron Tubes" as of Nov. 1, 1945 included the 715C, 719A, 2K25 (723AB), 726A-C, 1B23 (729A), 6AK5 (731A), and 3B24W (732A). Western Electric dropped this product line quickly: the 1946 catalog of the Graybar Electric Co. (WECO commercial distributor) lists only the 704A, 705A, 715C, 719A, 6AK5, and 3B24. However, several 700-series tubes were so widely used that they stayed in commercial demand for a generation. Ten years after these tubes were introduced, various manufacturers were offering the 705A, 707B, 715C, 719A, 721B, and 2K25; this despite years of intensive development of other radar tubes.

**Some applications.** These tubes and their successors formed the basis of dozens of radar systems. Because of constant changes in technology and in military requirements, systems were developed partially, developed and tested but not produced, or carried to operational success. Table 2 shows some operational systems using the 700-series tubes.

### TUBE DATA

**700-Type: UHF magnetrons.** WECO's first tubes of this type, with coaxial outputs and external magnets. Each was fixed-tuned to a different frequency in the 680-720 MHz band (700A: 710-720; 700D: 680-690) and produced a nominal pulse output of 40 kW at a 0.2% duty cycle. First, and possibly only, use was in the Navy Mk 3 (FC) and Mk 4 (FD) gunlaying radars, and in a retrofit transmitter assembly for the Mk 1 (FA) radar, with a pair of 701As as modulator and 702s in the TR switch. The Mk 1 had started out with a transmitter using a pair of WECO doorknob triodes and a relatively unsophisticated receiver; the new magnetron transmitter raised the output power about 10 dB, and a retrofit receiver with GL-446 lighthouse triodes improved performance by another 10 dB or so. The 4J42 magnetron was a tunable replacement for all four versions. British numbering: CV695 (700B), CV696 (700C), and CV699 (700D).

**701A: Modulator tetrode.** An early hard-tube pulser tube. It comprised four sets of electrodes, patterned after the 350A audio tetrode, in parallel. All grids were gold-plated; plate was molybdenum. Heater, 8 V at 7.5 A; maximum plate voltage 12 kV; dissipation 100 W. In the Mk 1 - Mk 4 radars, two tubes in parallel gave 2- $\mu$ s pulses of 10 kV at 12 A peak [18]. British number: CV677.

**702A, 702B: TR tubes.** Three-electrode disc-seal TR devices, with water-vapor filling, devised in late 1941 on a quick-reaction basis for use in the Mk 1, Mk 3, and Mk 4 radars [19]. Replaceable by the 729A (1B23).

**703A: UHF transmitting triode.** A small (2" dia.) single-ended doorknob tube, a dual numbering of the prewar 368AS. Filament rated at 1.15 V at 4.5 A, plate voltage 350, dissipation 25 W, nominal 1000-MHz output 2.5 W. Internal resonant frequency 1700 MHz [20]. This may have been the receiver RF-amplifier tube in early-production Mk 3 radars, before the GL-446 became available [21]. Far more 703As were used in the T-26/APT-2 "Carpet" and AN/APQ-2 "Rug" radar jammers, producing 3 to 20 watts and intended to counteract the

TABLE 1 - MULTIPLE NUMBERING

| <u>WEC</u> | <u>Other</u>  | <u>U. S.</u> | <u>RMA</u>  | <u>Westing-</u> | <u>Ray-</u>  | <u>REL</u> | <u>British</u> |
|------------|---------------|--------------|-------------|-----------------|--------------|------------|----------------|
| <u>Co</u>  | <u>WE/BTL</u> | <u>Army</u>  | <u>etc.</u> | <u>house</u>    | <u>theon</u> |            |                |
| 703A       | 368AS         |              |             |                 |              |            | CV679          |
|            | D-159764      |              |             |                 |              |            |                |
| 705A       | 378A          | VT-255       | 8021        |                 | RK705A       |            | CV3587         |
|            | D-159780      |              | (705WA)     |                 |              |            |                |
| 706A       |               |              |             | WL443           |              |            | CV3588         |
| 707B       |               |              |             |                 | QK26         |            | CV3689         |
| 708A       | D-160127      |              |             |                 |              |            | CV3590         |
|            | 1272Y         |              |             |                 |              |            |                |
| 710A       |               | VT-240       | 8011        | WL538           |              | 1          | CV46           |
|            |               | 588          |             |                 |              |            | E1046          |
|            |               |              |             |                 |              |            | VT90           |
|            |               |              |             |                 |              |            | 10E/97         |
| 717A       |               | VT-269       |             |                 |              |            | CV3594         |
| 722A       | 287A          |              | CE302       |                 |              |            |                |
| 723A       | 1439XQ        |              |             |                 |              | 31         | CV720          |
| 724A       | 1331          |              |             |                 |              |            | CV2656         |
| 725A       | 1330M         |              |             |                 |              |            | CV722          |
| 731A       | 403A          |              | 6AK5        |                 |              |            | CV850          |
| 732A       | 429T          |              | 3B24        |                 |              |            | CV812          |
|            | 1299XQ        |              | (3B24W)     |                 |              |            |                |

TABLE 2 - SOME TYPICAL APPLICATIONS

| <u>Radar</u>  | <u>Trans-</u> | <u>Clipper</u>  | <u>Trans-</u> | <u>TR</u>  | <u>Receiver</u> | <u>Receiver</u> | <u>Ref.</u> |
|---------------|---------------|-----------------|---------------|------------|-----------------|-----------------|-------------|
| <u>System</u> | <u>mitter</u> | <u>or</u>       | <u>mitter</u> | <u>and</u> | <u>Local</u>    | <u>IF</u>       |             |
|               | <u>Modu-</u>  | <u>Charging</u> | <u>Osc.</u>   | <u>ATR</u> | <u>Osc.</u>     | <u>Amps.</u>    |             |
|               | <u>lator</u>  | <u>Diode</u>    |               |            |                 |                 |             |
| Mk 3, Mk 4    | 2-701A        |                 | 700A-D        | 702A, B    | GL-446          |                 | [14]        |
| ASC           |               |                 |               |            | 707A            | 713A            |             |
| AN/APQ-13     | 2-5D21        | 705A            | 730AY         | 2-724B     | 2-723A          | 6AK5            | [15]        |
|               |               |                 |               |            |                 | & 717A          |             |
| AN/APS-4      | 2-1B22        | 3B24            | 725A          |            | 2-723AB         | 6AK5            | [16]        |
| AN/APS-15     | 715A          | None            | 725A          | 724A(?)    | 2-723A          | 6AC7            | [15]        |
|               |               |                 |               | & 1B24     |                 |                 |             |
| AN/MPG-1      | 2-5D21        | 719A            | 725A(?)       |            | 723A            | 6AC7            | [17]        |

ASC: Navy airborne sea-search radar.

Mk 3: Navy L-band shipboard radar for fire direction against surface targets.

Mk 4: Navy L-band shipboard air-defense radar.

AN/APQ-13: Army X-band airborne navigation and bombing radar.

AN/APS-4: Navy X-band airborne navigation and sea-search radar.

AN/APS-15: Army X-band airborne navigation and bombing radar.

AN/MPG-1: Army X-band harbor-defense radar.

Wuertzburg air-defense radar and other systems in the 200-720 MHz range. (There were other triode jammers: the AN/APQ-9 "Carpet III" used 8012s, and the AN/APT-5 employed a 3C22 lighthouse tube.) Tung-Sol second-sourced the 703A.

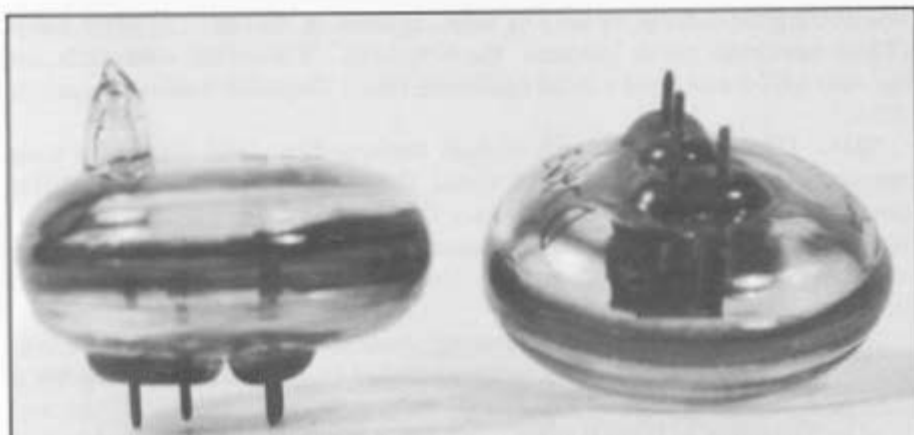
**704A: UHF rectifier.** A cathode-type detector diode, with three wire leads, apparently developed from a tube coded D-159765. Also numbered 225TQ. Small: only 1-5/16" high, 9/16" diameter, looking like a small lamp with a plate lead sealed into its side. Ratings: heater 4.5 V at 0.5 A; peak reverse voltage 1500, average forward current 10 mA. Used in the Navy LW radar test set as a detector for the wavemeter.

**705A: Vacuum rectifier.** A high-voltage diode on a special ceramic-disc four-pin base, with plate cap. Ratings were: thoriated-tungsten filament using 5 V at 5 A, peak reverse voltage 30 kV, average current 100 mA. Pairs of 705As were used in the pulsers of the AN/TPS-3 and AN/APQ-13. Second-sourced by various makers, as shown in Table 1; later "ruggedized" into the 705WA. Became an international success, being made eventually by STC in Britain (as the 2T/450E and P552/10E), by the Compagnie Thomson-Houston in France (the TH705A), and by NEC in Japan (the 1K75).

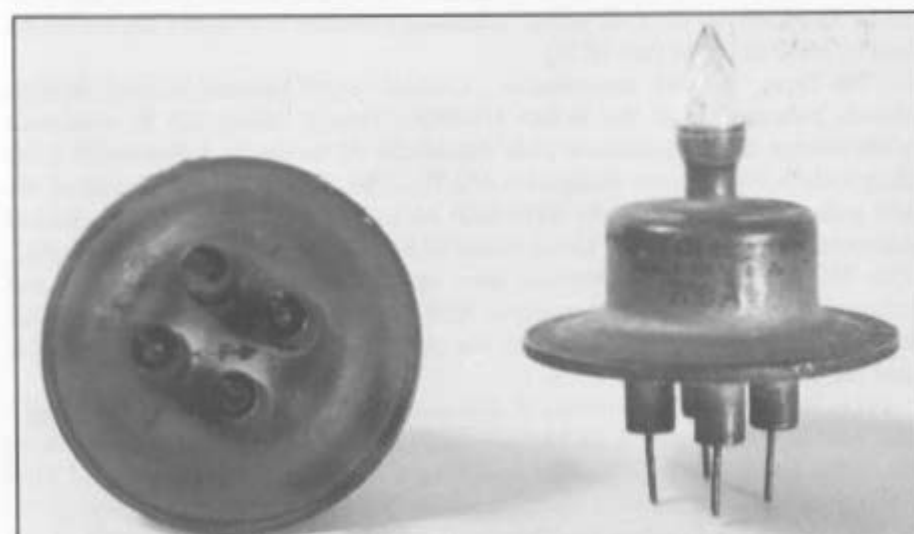
**706-Type: S-band magnetrons.** Coaxial-output external-magnet devices, closely patterned after the British CV3588. Heater ratings 6.9 V; maximum plate voltage 22 kV; maximum plate current 22 A; maximum pulse length 5  $\mu$ s; duty cycle 0.2%; average dissipation 450 W. The 706A-B-C was capable of 40-kW pulses, fixed-tuned in the 3019-3100 MHz band, and used in early S-band airborne and naval radars. There seems to have been a 706Y also (see photos). The 706AY through -GY versions were uprated substantially, to 206 kW, and covered 2914-3100 MHz, for example, 3038-3069 MHz for the 706EY. The 2J61 and 2J62 were tunable replacements for these types. Also see the related 714- and 718-types.

**707A, 707B: S-band klystrons.** A disc-seal octal-based design of 1942 vintage - the "McNally" tube, after J. O. McNally of BTL, who is better known for work on the 300A audio triode [22]. The operating frequency, between 1150 and 3750 MHz, was set by an external clamp-on cavity. Used as the local oscillator in the SO and AN/APN-7 radars, the Navy LAG signal generator, etc. Capable of 140 mW output. Second-sourced by Heintz and Kaufman, Sylvania, and Raytheon. The 707B was a temperature-compensated version. Raytheon developed it into the 2K28 by shortening the glass envelope slightly. British numbering: CV2651 (707A) and CV3689 (707B).

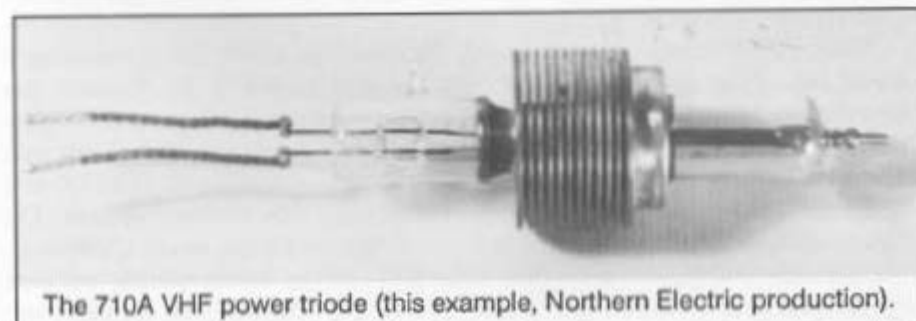
**708A: SHF triode.** A steel-cased, filament-type triode for grounded-grid mixer use. The silver-plated case was the grid terminal; the filament was brought out through two shielded pins, each forming a coaxial line, and the plate through two more. Filament voltage 1.7 V at 1.85 A, AC or DC. Used as a mixer in the Navy ASC and ASC-1 aircraft radars to develop a 60-MHz IF, and, apparently in the same assembly, in the 1942-vintage SE shipboard system. The 708A was the only tube mixer used in U. S. microwave radars, as the CV58 diode was the only British microwave tube mixer [23]: silicon diodes quickly replaced tubes because of superior performance. There was apparently an oscillator version of the 708A numbered D-160573 and 1301M; the 708A was really a power tube, rated at 350 V, 50 mA, and 15 watts dissipation.



Two views of the 703A UHF triode, of the "doorknob" family.



The 708A metal grounded-grid SHF mixer triode, with its coaxial filament and plate connections.



The 710A VHF power triode (this example, Northern Electric production).

*Photos: L. A. Sibley*

**709A: S-band TR tube.** A three-electrode disc-seal cavity TR device made, as a quick expedient, by adding gas to a 712A; used in several Army radars [24]. British numbering: CV2653.

**710A: VHF-UHF transmitting triode.** An external-anode unit capable of 80 watts' dissipation with forced-air cooling. Filament power was 8.25 V at 7.1 A. Maximum plate-voltage rating, 10 kV. As designed by GEC in Britain in 1939, it was the first of a "micropup" series intended for use at and above 200 MHz [25]. Able to produce several kilowatts of pulse power at 600 MHz, it was applied in 200-MHz air-interception and ASV radars. Adapted for U. S. - Canadian manufacture, it was used in pairs in the Philco ASE and ASE-1 radars for Navy aircraft (adaptations of the British ASV Mk II), at about 175 MHz, and apparently in the SCR-540 200-MHz air-interception radar, which was patterned after the British Mk IV design. Northern Electric produced 710As for use in SCR-540s and other radars made by Research Enterprises Limited (REL) in Toronto (not to be confused with the Radio Engineering Laboratories in the U. S.) for both Canadian and U. S. use. The appendix by Colin MacKinnon provides an excellent overview of the 710A as used in Australian radars. The 710A was presumably the design idea for the (larger) 6C24 introduced by RCA in 1946. There was also a Sperry 710 X-band klystron and a National Electronics 710/6011 gas rectifier, both distinct from the 710A.

**711A: Oscillator.** Device used in British equipment. Dual-numbered 1287Y. Other details are lacking. The 711A apparently did not receive a CV-number, and seems not to have turned up in postwar surplus stocks in the U. S., so may not have gone into actual production.

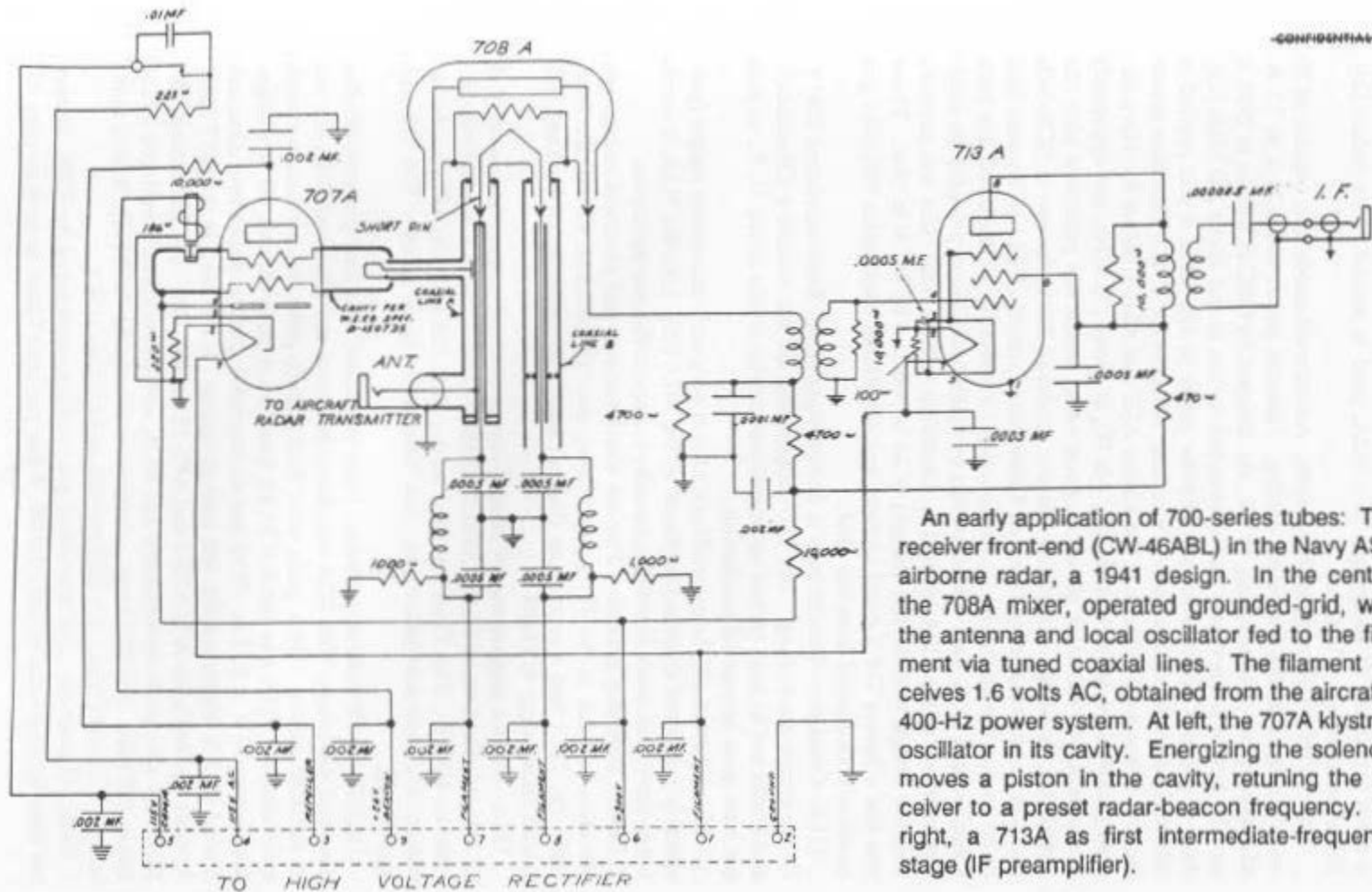
**712A: Klystron (?)** Local-oscillator tube in very early microwave radars (presumably a disc-seal klystron), replaced by the 707A [26]. Like the 711A, it seems not to have been made in enough quantity to survive the war as surplus.

**713A: Receiving pentode.** Physical characteristics and electrical ratings are the same as those of the 717A (see below); the 713A used an all-bakelite base, while the 717A had a metal-ring (bantal) base. Second-sourced by Tung-Sol. British numbering: CV3593.

**714A: S-band magnetron.** A coaxial-output external-magnet design rated at 22 kW out, fixed-tuned in the 3280-3320 MHz band. The AY version was up-rated to 165 kW. The 714A was used on the SCR-520 and AN/APS-2 airborne radars, very early microwave sets. See 706-type for basic ratings. The 718-type was related.

**715A-Type: Modulator tetrodes.** Pulse amplifiers on a four-pin ceramic-disc base with plate cap. The 715A was developed from the 356A and 701A for use in airborne radars. Both grids were gold-plated; plate was zirconium-coated molybdenum. 715A was rated at 14 kV peak, 15 A peak current, 60 W dissipation; heater 27 V at 2.15 A. 715B had an improved grid for cooler operation and carried slightly higher voltage and current ratings. It was used in the MIT Mod. 3 pulser and in Philco AN/APS-2 and APS-15 radars. The 715C had ratings like 715B; was also made by Raytheon and RCA, and was eventually replaced by the Eimac 4PR60A. The 5D21 was a development from the 715B [27]. British numbering: CV2654 (715A), CV2655 (715B), and CV598 (715C).

**716A: Thyatron.** Grid-controlled gas rectifier, superseded by 722A. It may not have actually been manufactured: it has not been found in early surplus ad-



An early application of 700-series tubes: The receiver front-end (CW-46ABL) in the Navy ASC airborne radar, a 1941 design. In the center, the 708A mixer, operated grounded-grid, with the antenna and local oscillator fed to the filament via tuned coaxial lines. The filament receives 1.6 volts AC, obtained from the aircraft's 400-Hz power system. At left, the 707A klystron oscillator in its cavity. Energizing the solenoid moves a piston in the cavity, retuning the receiver to a preset radar-beacon frequency. At right, a 713A as first intermediate-frequency stage (IF preamplifier).

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**717A: Receiving pentode.** Octal mushroom-bulb device, developed ca. 1941 from the prewar 386A and later modified into the 6AJ5 and 6AK5. Heater rating 6.3 V at 0.175 A; transconductance 4100  $\mu$ mhos. Used in WECO communications equipment (the BC-942 and R-28/ARC-5 receivers), navigation gear (the BC-733 localizer receiver), as well as the 30- or 60-MHz IF amplifiers in radars (SCR-717, AN/APQ-7 and -13, etc.). As a radar IF amplifier, it was preferable to the older 6AC7 and less desirable than the later 6AK5.

**718-Type: S-band magnetrons.** A long-life (2000-hr) development of the 706-type, fixed-tuned in the 2720-2890 MHz band and producing 193 kW. Versions were 718A through -E and -AY through -GY. As an example, the 718DY operated between 2720 and 2890 MHz. See 706-type for basic ratings.

**719A: Vacuum diode.** A cathode-type clipper tube for use in radar pulsers, 6" high, on a four-pin ceramic-disc base with plate cap. Heater 7 V at 7 A; peak reverse voltage 25 kV; peak forward current 10 A; average current 0.5 A. A specialized design not intended for rectifier service.

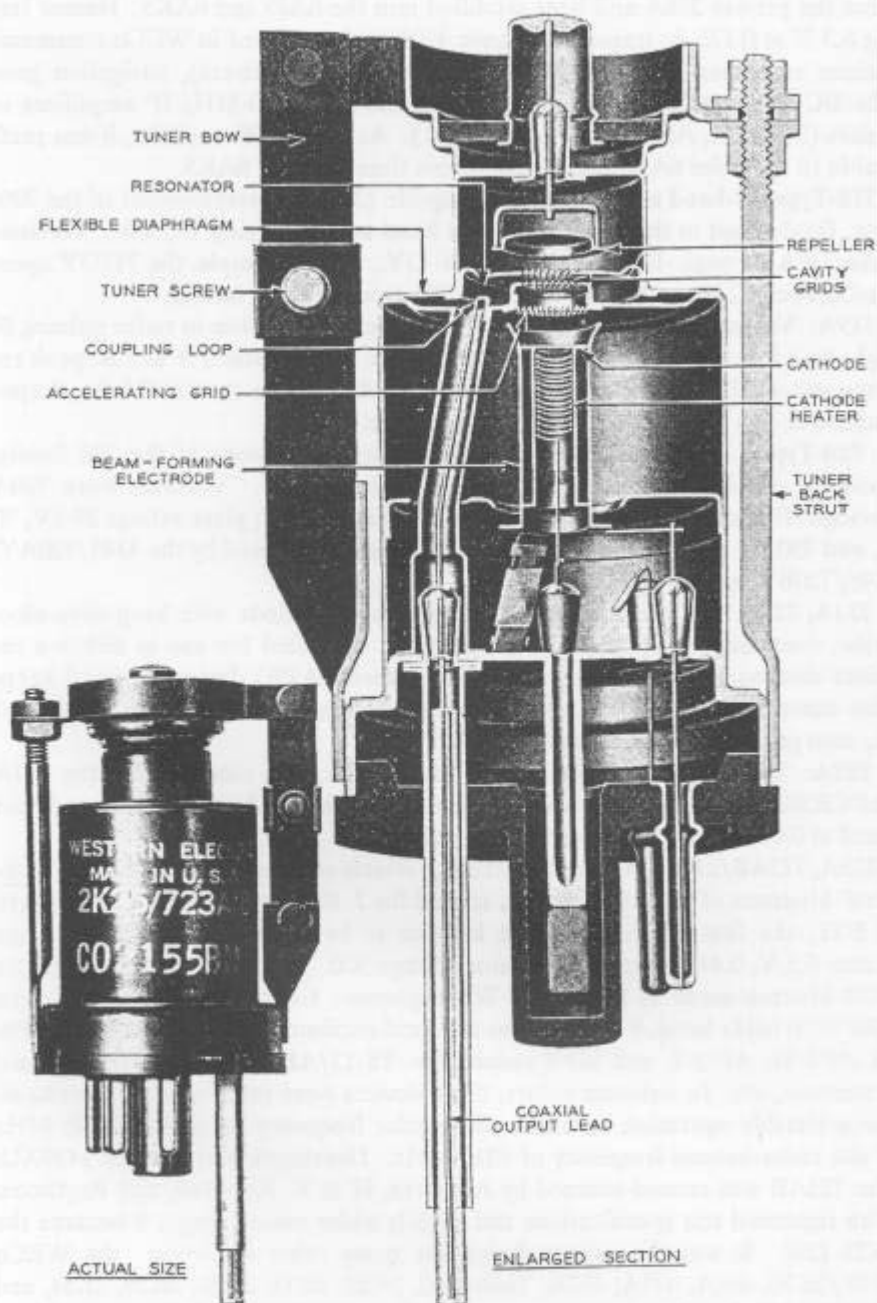
**720-Type: S-band magnetrons.** Double-length versions of the 718 family, good for one-MW pulses in the same frequency band. Versions were 720A through -E and -AY through -EY. Heater rating 13.9 V; plate ratings 27 kV, 70 A, and 750 W; duty cycle 0.1%; pulse length 5  $\mu$ s. Replaced by the 4J45/720AY, 4J46/720BY, and 4J47/720CY.

**721A, 721B: TR tubes.** Large (2" long) disc-seal diode with keep-alive electrode, containing water vapor and hydrogen. Intended for use as either a receiver-disconnect (TR) or transmitter-disconnect (ATR) device. Typical keep-alive current 200  $\mu$ A. Was used in S-band radars, including the SCR-545 and SL; also produced by Raytheon [28].

**722A: Thyatron.** Grid-controlled gas rectifier, also numbered as the 287A and CE302. Used as a pulser in the SE radar. (The 287A was a mercury device rated at 0.64 A and 2500 V, about 6" high.)

**723A, 723AB/2K25: X-band klystrons.** Widely successful metal "Pierce-Shepherd" klystrons of late 1942 vintage, named for J. R. Pierce and W. G. Shepherd of BTL, the first low-voltage 3-cm klystron to be made in quantity. Ratings: heater 6.3 V, 0.44 A; typical resonator voltage 300. It competed with the larger 417A klystron made by Sperry and Westinghouse. Capable of 20-40 mW in the 8700-9550 MHz band, it was used as the local oscillator in the AN/APS-6, APS-10, APS-31, APQ-7, and SO-3 radars, the TS-13/AP and H-P Type G signal generators, etc. In airborne radars, these devices were often used in pairs to allow selectable operation on either the regular frequency of, usually, 9375 MHz or the radar-beacon frequency of 9310 MHz. Developmental number 1439XQ. The 723AB was second-sourced by Amperex, H & K, Ken-Rad, and Raytheon. With tightened test specifications and slightly wider tuning range, it became the 2K25 [29]. It was the source design for many other klystrons: the WECO 397A/2K56, 406A, 431A, 452A, 726A-B-C, 2K22, 2K23, 2K26, 2K29, 2K54, and 2K55; and various Raytheon products like the QKK1313 and RK5976, the latter promoted as late as 1955.

The frequency of oscillation was slightly sensitive to ambient air pressure: the WECO data sheet includes a curve showing the effect of varying altitude. Going from sea level to 25,000 feet, in the absence of automatic frequency control,



The 2K25/723AB klystron and its internal construction.  
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caused a drift of about 10 MHz. As another quirk, the resonator was connected to the tube shell, requiring that the tube body operate 300 V below ground. This was a source of surprise to unwary technicians.

British makers designed near-equivalents of the 723A: the EMI CV322 and the British Thomson-Houston CSS2 [30].

**724A, 724B: X-band TR tubes.** TR diodes, similar to the 721A but smaller [31]. Also numbered 1331. The "B" was a temperature-compensated version of the 721A. Typical keep-alive current was 100  $\mu$ A. Used as the TR and ATR tubes in X-band radars like the AN/APS-6 and -15. Second-sourced by Sylvania.

**725A: X-band magnetron.** A waveguide-output, external-magnet unit, fixed-tuned at 9375 MHz ( $\pm 30$  MHz), using 12 resonators and interchangeable with the 2J21. Developed during 1942. Heater rating 6.3 V; plate voltage 13 kV, peak current 13 A, duty cycle 0.1%; pulse width, 2.1  $\mu$ s. Output was 55 kW, with input of 10 A at 14 kV. Used in numerous airborne radars: AN/APS-3, APS-4, APS-15, etc. Also numbered 1330M. Second-sourced by Northern Electric and Raytheon; total production 300,000. Replaceable by 2J53. British Thomson-Houston developed an equivalent, the MX57 (2), also coded CV209.

**726-Type: S-band klystrons.** Externally the same as the 723AB, but frequency ranges were 3.2-3.4 (726A), 2.9-3.2 (726B), and 2.7-2.9 GHz (726C). Made in moderate quantity and second-sourced by Raytheon. Specific application examples not known, but was widely used in later versions of equipment that had employed the 707-type klystron - for example, there seems to have been a receiver assembly for the SE radar that substituted for one with 707A oscillator [32]. The 726As observed use a simple fixed-welded strap for the nonadjustable side of the tuning mechanism, whereas 726Cs have been found with either this fixed design or the threaded-rod factory-settable design used in the 723A.

**727A: Thyatron.** A cold-cathode gas triode, similar to the 359A and replaceable by the 395A. The latter were  $\frac{1}{2}$ " in diameter and had three pins.

**728-Type: L-band magnetrons.** A series of devices (with coaxial outputs and external magnets), suitable for 275 kW output in the 900-970 MHz area. The group included the 728A through -J and -AY through -GY. Used in fire-control and search radars that replaced the Mk 3 and Mk 4. These units were replaceable by the 4J51 (1443M) tunable unit.

**729A: L-band TR tube.** A dual numbering of the 1B23 double-gap gas TR tube, a device for radars in the approximate frequency range of 950 to 1220 MHz. Replaced the 702A with use of a modification kit.

**730A: X-band magnetron.** Identical to the 725A, but with input leads relocated 180 degrees from the output waveguide. Also numbered 1384M.

**731A: Receiving pentode.** A dual numbering of the 403A/6AK5. Actual production apparently was numbered 6AK5. The 6AK5 was preferred over earlier types for IF amplifiers, but was restricted to airborne applications for a time due to lack of production capacity.

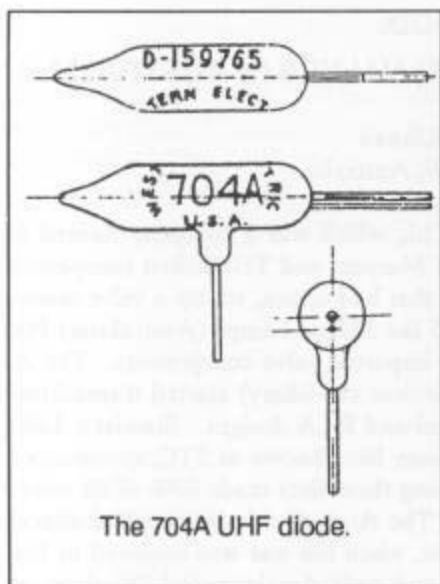
**732A: Vacuum rectifier.** A scaled-down and rebased version of the 705A. Actual production was apparently under the other numbers, particularly 3B24, in Table 1. It was a four-pin, top-cap, tubular type; with thoriated-tungsten filament using 5 V at 3 A, peak reverse voltage 20 kV, average current 60 mA. "Ruggedized" into the 3B24W.

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