Discrete Electronic Components

A. Discrete Electronic Components - Vacuum Tubes

1. General

   a. In electronics, a vacuum tube, electron tube, or (outside North America) thermionic valve or just valve, is a device used to amplify, switch or modify a signal by controlling the movement of electrons in an evacuated space. Vacuum tubes were critical devices in electronics technology, leading to the development and commercialization of such technologies as radio broadcasting, television, radar, high fidelity sound reproduction, telephone, analog and digital computers, and industrial process control.

   b. For most purposes, the vacuum tube has been replaced by the much smaller, less power-hungry, and less expensive transistor, either as a discrete device or in an integrated circuit. However, tubes are still used in specialized applications, such as in high-end audio systems, instrument amplifiers and high power RF transmitters. Cathode ray tubes are still used as a display device in television sets and computer monitors (although they face serious competition from LCD and plasma displays), and magnetrons are the source of microwaves in microwave ovens

   c. Vacuum tubes, or thermionic valves, are arrangements of electrodes in a vacuum within an insulating, temperature-resistant envelope. Although the envelope is classically glass, power tubes often use ceramic and metal. The electrodes are attached to leads which pass through the envelope via an air tight seal. On most tubes, the leads are designed to plug into a tube socket for easy replacement.

   d. The simplest vacuum tubes resemble incandescent light bulbs in that they have a filament sealed in a glass envelope which has been evacuated of all air. When hot, the filament releases electrons into the vacuum: a process called thermionic emission. The resulting negatively-charged cloud of electrons is called a space charge. These electrons will be drawn to a metal plate inside the envelope, if the plate (also called the anode) is positively charged relative to the filament (or cathode). The result is a flow of electrons from filament to plate. This cannot work in the reverse direction because the plate is not heated and cannot emit electrons. This very simple example described can thus be seen to operate as a diode: a device that conducts current only in one direction. The vacuum tube diode conducts conventional current from plate (anode) to the filament (cathode); this is the opposite direction to the flow of electrons (called electron current).

e. The vacuum tube is a voltage-controlled device, which means that the relationship between the input and output circuits is determined by a transconductance function. The solid-state device most closely analogous to the vacuum tube is the JFET, although the vacuum tube typically operates at far higher voltage (and power) levels than the JFET.

2. Diode Vacuum Tube

   a. John Ambrose Fleming had worked for Edison; in 1904, as scientific adviser to the Marconi company, he developed the "oscillation valve" or kenotron. Later known as the Fleming Valve and then the diode, it allowed electric current to flow in only one direction, enabling the rectification of alternating current. Its operation is described in greater detail in the previous section.

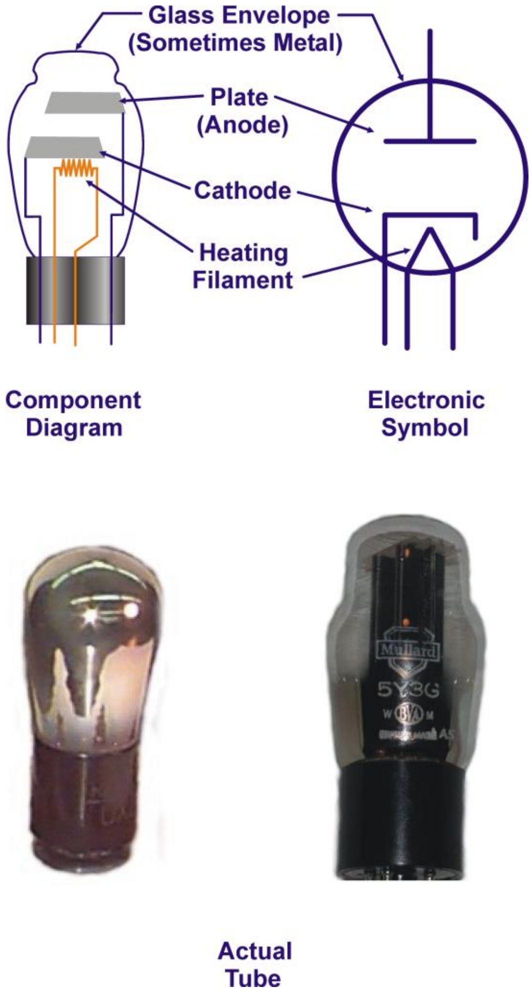


Figure 1, Vacuum-Tubes-001 Diode Vacuum Tube

b. Some diodes are filled with gas to create a voltage regulator. The OA2 tube is such a device. The gas within the tube ionizes at a specific voltage. The ionizing voltage stays constant even if the applied voltage is higher. This characteristic allows the tube to be used as a voltage regulator.

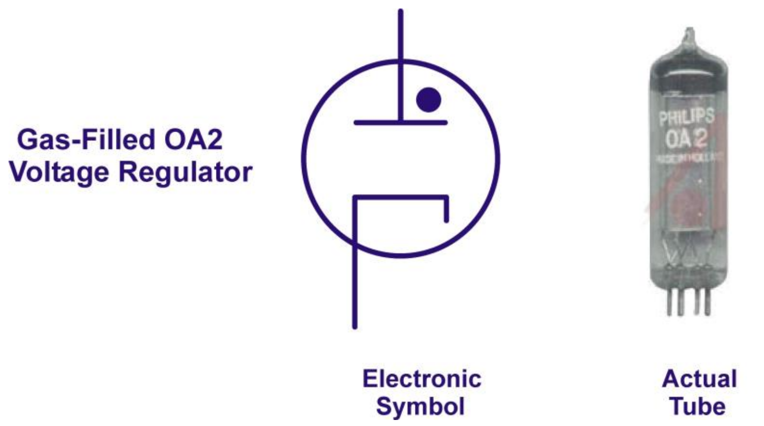


Figure 2, Vacuum-Tubes-002 Voltage Regulator Tube

3. Triode Vacuum Tube

   a. In 1907 Lee De Forest placed a bent wire serving as a screen, later known as the "grid" electrode, between the filament and plate electrode. As the voltage applied to the grid was varied from negative to positive, the number of electrons flowing from the filament to the plate would vary accordingly. Thus the grid was said to electrostatically "control" the plate current. The resulting three-electrode device was therefore an excellent and very sensitive amplifier of voltages. DeForest called his invention the "Audion". In 1907, DeForest filed U.S. Patent 879532 for a three-electrode version of the Audion for use in radio communications. The device is now known as the triode. De Forest's device was not strictly a vacuum tube, but clearly depended for its action on ionisation of the relatively high levels of gas remaining after evacuation. The De Forest company in its Audion leaflets warned against operation which might cause the vacuum to become too hard. The Finnish inventor Eric Tigerstedt significantly improved on the original triode design in 1914, while working on his sound-on-film process in Berlin, Germany. The first true vacuum triodes were the Pliotrons developed by Irving Langmuir at the General Electric research laboratory (Schenectady, New York) in 1915. These were closely followed by the French 'R' Type which was in widespread use by the allied military by 1916. These two types were the first true vacuum tubes. Historically, vacuum levels in production vacuum tubes typically ranged between 10 µPa to 10 nPa.

b. The non-linear operating characteristic of the triode caused early tube audio amplifiers to exhibit harmonic distortions at low volumes. This is not to be confused with the overdrive that tube amplifiers exhibit at high volume levels (known as the tube sound). To remedy the low volume overdrive problem, engineers plotted curves of the applied grid voltage and resulting plate currents, and discovered that there was a range of relatively linear operation. In order to use this range, a negative voltage had to be applied to the grid to place the tube in the "middle" of the linear area with no signal applied. This was called the idle condition, and the plate current at this point the "idle current". Today this current would be called the quiescent or standing current. The controlling voltage was superimposed onto this fixed voltage, resulting in linear swings of plate current for both positive and negative swings of the input voltage. This concept was called grid bias.

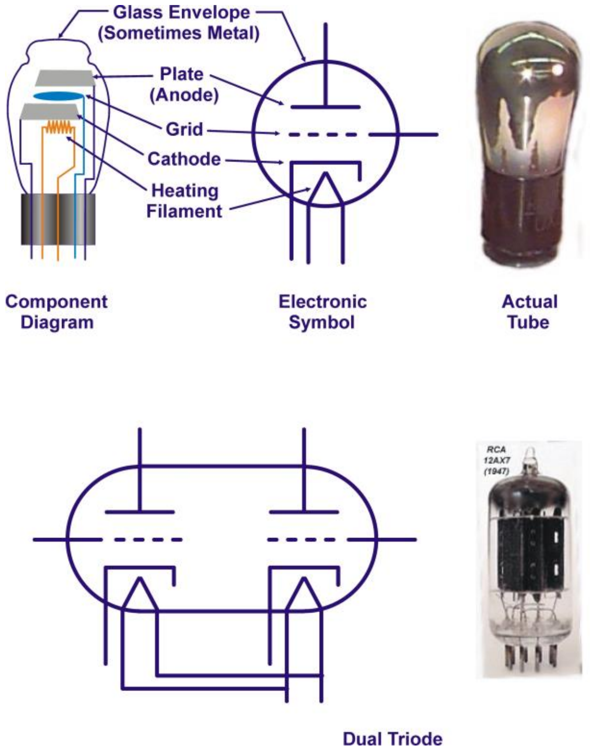


Figure 3, Vacuum-Tubes-003 Triode Vacuum Tube

c. Batteries were designed to provide the various voltages required. "A" batteries provided the filament voltage. These were often rechargeable - usually of the lead-acid type ranging from 2 to 12 volts (1-6 cells) with single, double and triple cells being most common. In portable radios, flashlight batteries were sometimes used. Throughout most of the world this is known as the LT (low tension battery).

d. The "B" batteries provided the plate voltage. These were generally of dry cell construction, containing many small 1.5 volt cells in series and typically came in ratings of 22.5, 45, 67.5, 90 or 135 volts, being made of series connected 1.5 volt zinc-carbon batteries. To this day, plate voltage is referred to as B+, but only in America. The rest of the world calls this supply the HT (high tension) supply or battery.

e. Some sets used "C" batteries to provide grid bias, although many circuits used grid leak resistors, voltage dividers or cathode bias to provide proper tube bias. Most of the world calls this simply the 'grid bias battery'.

4. Pentode Vacuum Tube

   a. When triodes were first used in radio transmitters and receivers, it was found that they had a tendency to oscillate due to parasitic anode to grid capacitance. Many complex circuits were developed to reduce this problem (e.g. the Neutrodyne amplifier), but proved unsatisfactory over wide ranges of frequencies. It was discovered that the addition of a second grid, located between the control grid and the plate and called a screen grid could solve these problems. A positive voltage slightly lower than the plate voltage was applied to it, and the screen grid was bypassed (for high frequencies) to ground with a capacitor. This arrangement decoupled the anode and the first grid, completely eliminating the oscillation problem. An additional side effect of this second grid is that the Miller capacitance is also reduced, which improves gain at high frequency. This two-grid tube is called a tetrode, meaning four active electrodes.

   b. However, the tetrode had a problem too: the positive voltage on the second grid accelerated the electrons, causing them to strike the anode hard enough to knock out secondary electrons. These could then be captured by the second grid, reducing the plate current and the amplification of the circuit. This effect was sometimes called "tetrode kink". Again the solution was to add another grid, called a suppressor grid. This third grid was biased at either ground or cathode voltage and its negative voltage (relative to the anode) electrostatically suppressed the secondary electrons by repelling them back toward the anode. This three-grid tube is called a pentode, meaning five electrodes.

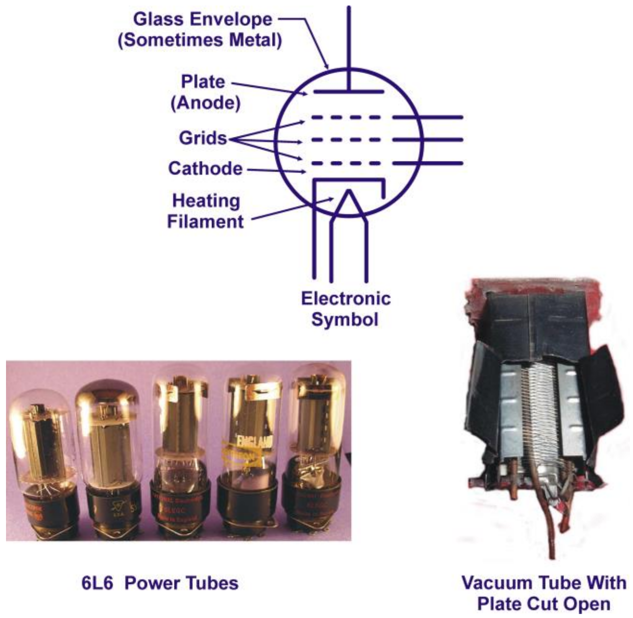
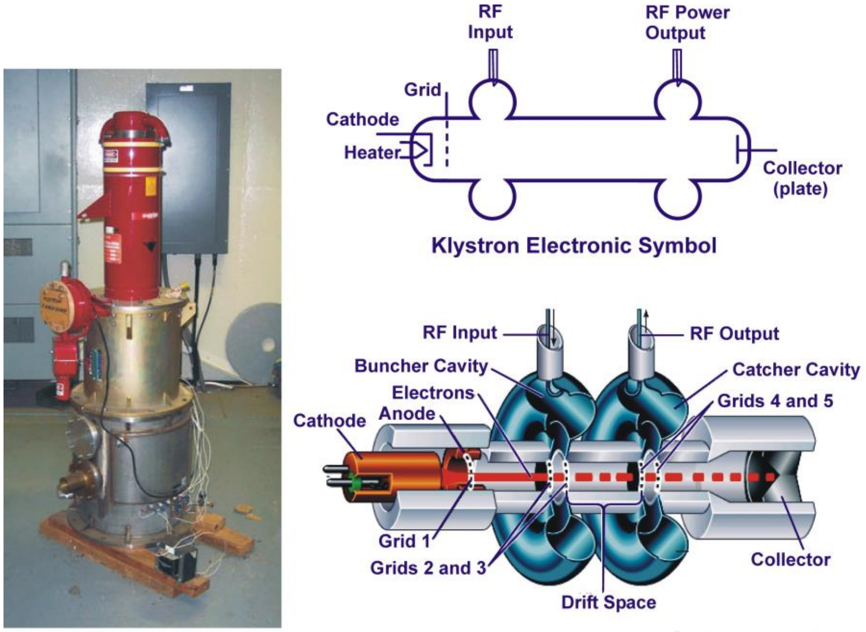


Figure 4, Vacuum-Tubes-004 Pentode Vacuum Tube

5. Klystrons



Actual Klystron

Klystron Construction Diagram (Two Cavity Klystron)

Figure 5, Vacuum-Tubes-005 Klystron Exploded View

a. A Klystron is very basically similar to an organ pipe, both in appearance and operational principle.

b. In an organ pipe:

1) Blowing into the organ pipe produces a flow of air.

2) Flowing air excites vibrations in the cavity of the whistle.

3) The vibrations flow into the surrounding air as sound waves.

c. In a klystron: (Refer to Figure "Vacuum-Tubes-006")

1) The electron gun ❶ produces a flow of electrons.

2) The bunching cavities ❷ regulate the speed of the electrons so that they arrive in bunches at the output cavity.

3) The bunches of electrons excite microwaves in the output cavity of the klystron. ❸

4) The microwaves flow into the waveguide, which transports ❹em to the accelerator.

5) The electrons are absorbed in the beam stop.

❺

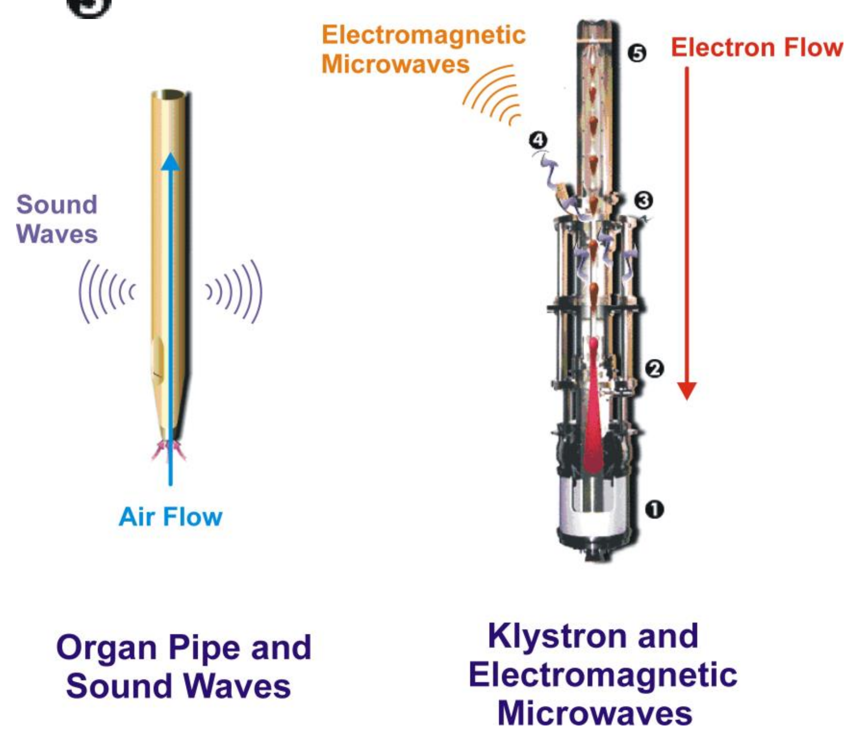


Figure 6, Vacuum-Tubes-006 Klystron/Organ Similarities

d. Klystrons are used as an oscillator or amplifier at microwave and radio frequencies to produce both low power reference signals for superheterodyne radar receivers and to produce high-power carrier waves for communications and the driving force for linear accelerators. It has the advantage (over the magnetron) of coherently amplifying a reference signal and so its output may be precisely controlled in amplitude, frequency and phase. Many klystrons have a waveguide for coupling microwave energy into and out of the device, although it is also quite common for lower power and lower frequency klystrons to use coaxial couplings instead. In some cases a coupling probe is used to couple the microwave energy from a klystron into a separate external waveguide.

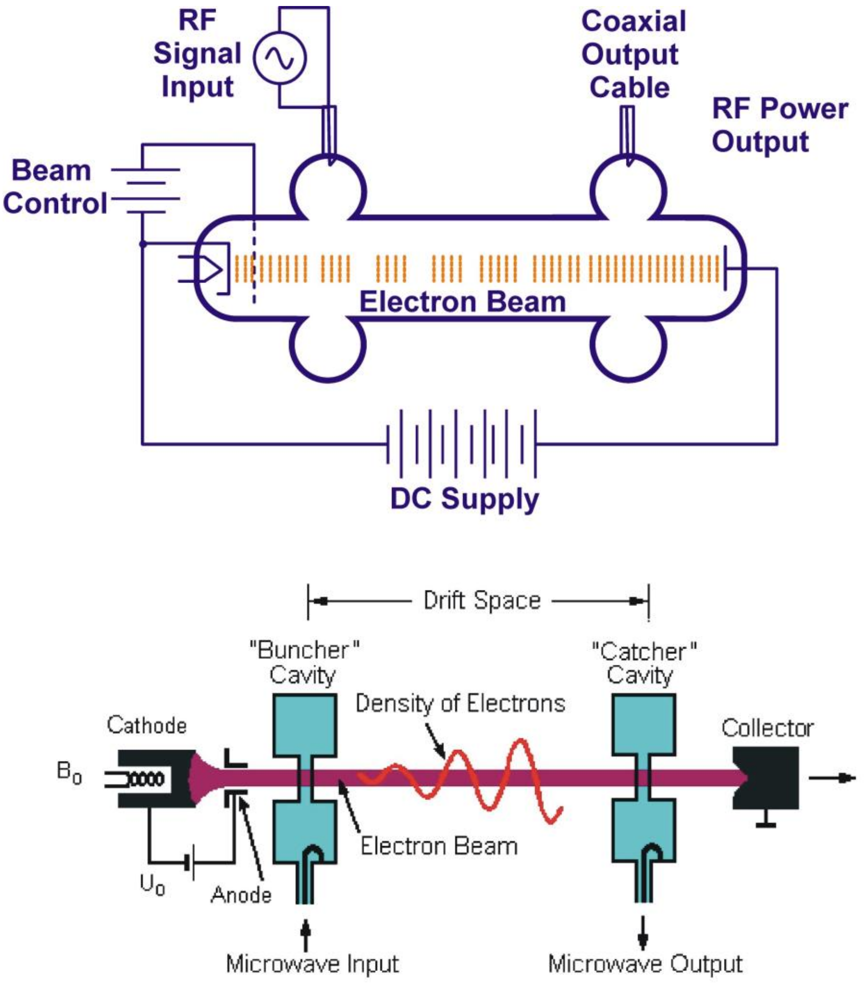
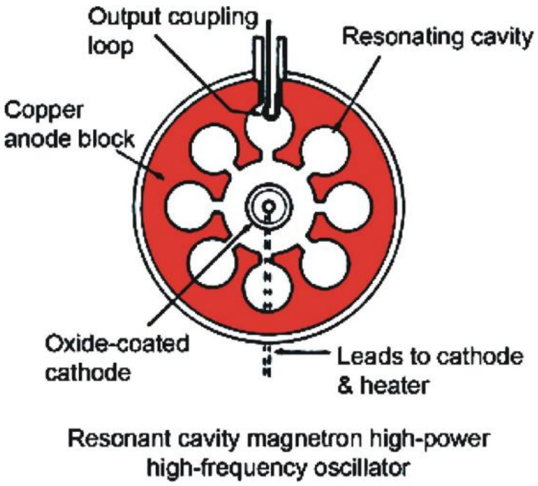


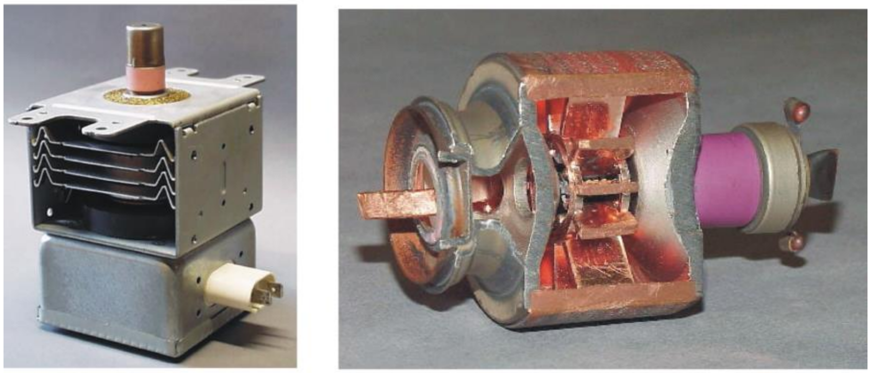
Figure 7, Vacuum-Tubes-007 Klystron Basic Circuit Application

6. Cavity Magnetrons

Magnetron Electronic Symbol



Magnetron Construction Diagram



Actual Magnetron

Figure 8, Vacuum-Tubes-008 Magnetron Circuit Symbol

a. A cavity magnetron is a high-powered vacuum tube that generates coherent microwaves. They are commonly found in the microwave oven, as well as various radar applications.

b. All cavity magnetrons consist of a hot filament (cathode) kept at or pulsed to a high negative potential by a high-voltage direct-current power supply. The cathode is built into the center of an evacuated, lobed, circular chamber. A perpendicular magnetic field is imposed by a permanent magnet. The magnetic field causes the electrons, attracted to the (relatively) positive outer part of the chamber, to spiral outward in a circular path rather than moving directly to this anode. Spaced about the rim of the chamber are cylindrical cavities. The cavities are open along their length and so connect the common cavity space. As electrons sweep past these openings they induce a resonant high frequency radio field in the cavity, which in turn causes the electrons to bunch into groups. A portion of this field is extracted with a short antenna that is connected to a waveguide (a metal tube usually of rectangular cross section). The waveguide directs the extracted RF energy to the load, which may be a cooking chamber in a microwave oven or a high gain antenna in the case of radar.

c. The sizes of the cavities determine the resonant frequency, and so the frequency of the emitted microwaves. However, the frequency is not precisely controllable; but this is not a problem in many applications such as heating or some forms of radar where the receiver can be synchronised with the nonprecision output. Where precise frequencies are required, other devices such as the klystron are used. The voltage applied and the characteristics of the cathode determine the power of the device.

d. The magnetron is a fairly efficient device. In a microwave oven, for instance, a 1100 watt input will generally create about 700 watts of microwave energy, an efficiency around 65%. This is far more efficient than the klystron, which typically operates around 30%. Modern solid state microwave sources typically operate around 25 to 30%, and are used primarily because they can generate a wide range of frequencies. Thus the magnetron remains in widespread use in roles which require high power, but where precise frequency control is unimportant.

e. In radar devices the waveguide is connected to an antenna, which may be a slotted waveguide or a conical feedhorn pointing into a parabolic reflector. The magnetron is operated with very short high intensity pulses of applied voltage, resulting in a short pulse of microwave energy being emitted. A small portion of this energy is reflected back to the antenna and the waveguide where it is directed to a sensitive receiver. With further signal processing the signal is ultimately displayed as a radar map on a screen.

f. In microwave ovens the waveguide leads to a radio frequency transparent port into the cooking chamber. It is important that there be food in the oven when it is operated so that these waves are absorbed, rather than reflecting back into the waveguide where the intensity of standing waves can cause arcing. The arcing, if allowed to occur for long periods, will destroy the magnetron. If a very small object is being microwaved, it is recommended to add a glass of water as an energy sink, although care must be taken not to "superheat" the water.

g. Simple two-pole magnetrons were developed in the 1920s by Albert Hull at General Electric's Research Laboratories (Schenectady, New York), as an outgrowth of his work on the magnetic control of vacuum tubes in an attempt to work around the patents held by Lee DeForest on electrostatic control. The two-pole magnetron, also known as a split-anode magnetron, had relatively low efficiency. The cavity version (properly referred to as a resonant-cavity magnetron) proved to be far more useful.

h. There was an urgent need during radar development in World War II for a high-power microwave generator that worked in shorter wavelengths - around 10 cm rather than 150 cm - available from tube-based generators of the time. It was known that a multi-cavity resonant magnetron had been developed in 1935 by Hans Hollmann in Berlin. However the German military considered its frequency drift to be undesirable, and based their radar systems on the klystron instead. It was primarily for this reason that German night fighter radars were never a match for their British counterparts.

i. In 1940, at the University of Birmingham in the UK, John Randall and Dr. Harry Boot produced a working prototype similar to Hollman's cavity magnetron, but added liquid cooling and a stronger cavity. Randall and Boot soon managed to increase its power output 100-fold. Instead of giving up on the magnetron due to its frequency inaccuracy, they instead sampled the output signal and synced their receiver to whatever frequency was actually being generated.

j. Because France had just fallen to the Nazis and Britain had no money to develop the magnetron on a massive scale, Churchill agreed that Sir Henry Tizard should offer the magnetron to the Americans in exchange for their financial and industrial help. By September, the Massachusetts Institute of Technology had set up a secret laboratory to develop the cavity magnetron into a viable radar. Two months later, it was in mass production, and by early 1941, portable airborne radar were being installed into American and British planes[1].

k. An early 6kW version, built in England by GECRL at their Wembley factory and given to the U.S. government in September 1940, was called "the most valuable cargo ever brought to our shores" (see Tizard Mission). At the time the most powerful equivalent microwave-producer available in the US (a klystron) had a power of only ten watts. The cavity magnetron was widely used during World War II in microwave radar equipment, and is often credited with giving Allied radar a considerable performance advantage over German and Japanese radars, thus directly influencing the outcome of the war.

l. Short wave centimetric radar, which was made possible by the cavity magnetron, allowed for the detection of much smaller objects and the use of much smaller antennas. The combination of the small sized cavity magnetron, small antennas and high resolution allowed small, high quality radars to be installed in aircraft. They could be used by maritime patrol aircraft to detect objects as small as a submarine periscope, which allowed aircraft to attack and destroy submerged submarines which had previously been undetectable from the air. Centimetric contour mapping radars like H2S improved the accuracy of Allied bombers used in the strategic bombing campaign. Centimetric gun laying radars were likewise far more accurate than the older technology. They made the big gunned Allied battleships more deadly and along with the newly developed proximity fuze made anti-aircraft guns much more dangerous to attacking aircraft. The two coupled together and used by anti-aircraft batteries, placed along on the German V-1 flying bomb flight paths to London, are credited with destroying many of the flying bombs before they reached their target.

Figure 9, Vacuum-Tubes-009 First Cavity Magnetron

m. Since then, many millions of cavity magnetrons have been manufactured; some for radar, but the vast majority for another application far more domestic — the microwave oven. The use in radar itself has dwindled to some extent, as more accurate signals have generally been needed and developers have moved to klystron and travelling wave tube systems for these needs.

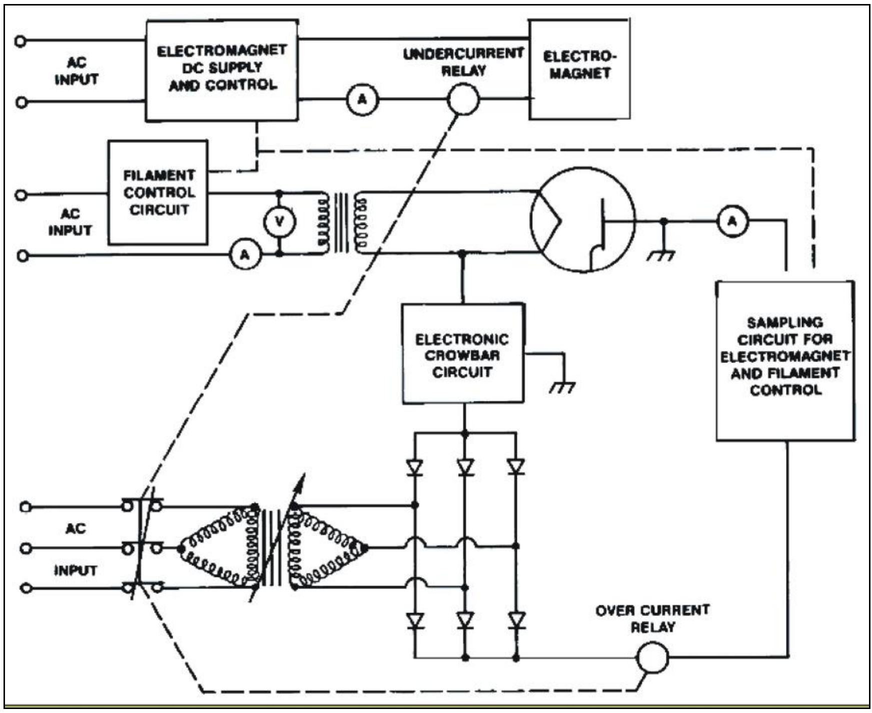
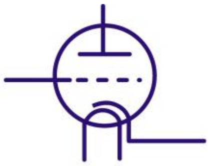


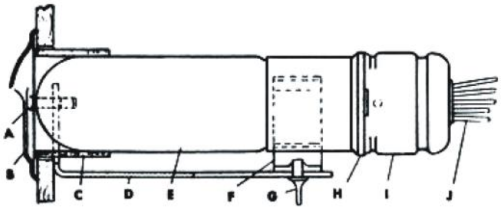
Figure 10, Vacuum-Tubes-010 Simple Magnetron Application Circuit

Figure 11, Vacuum-Tubes-011 Damaged Magnetron

7. "Magic-Eye" Tubes



Magic-Eye Electronic Symbol



A—Art Head Screws; B—Escutcheon; C—Fibre Light Shield; R—Mounting Bracket; E—Magic Eye Tube (not included); F—Adjustable Spring Clip; G—Wing Screw; H—Bakelite Socket; I—Black Japanned Metal Socket Cover; J—Color Coded Cable, 22″ long.

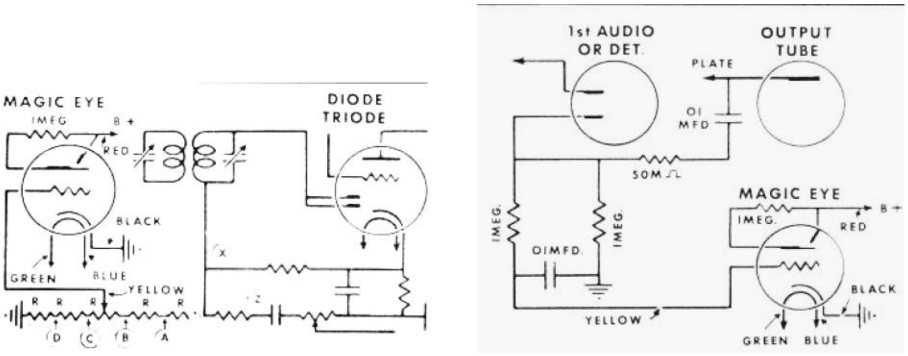
Magic-Eye Construction Diagram

Actual Magic-Eye

Figure 12, Vacuum-Tubes-012 "Magic-Eye" Tube Electronic Symbol

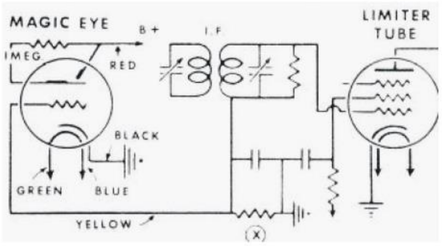
a. The "Magic Eye" vacuum tube is used as a tuning indicator inside some top class receivers. The top of the tube is a circle with green phosphors. Its wideness is a funcion of the strenght of the received carrier. Inside this tube there is a little triode used as preamplifier of the AGC (Automatic Gain Control).

b. The tuning indicator tube, or "Magic Eye" as it is was introduced by RCA, was used to display the optimum signal tuning point of a tuner/receiver, or the peak signal level of a preamplifier or tape recorder. The main benefit in tuning reception was for FM tuners where the exact tuning point was harder to determine than for AM. They were cool looking then and still are.



Superheterodyne Circuit

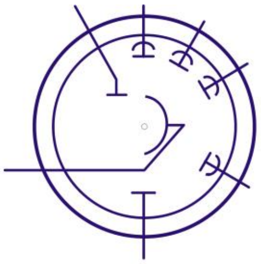
Recorder Circuit



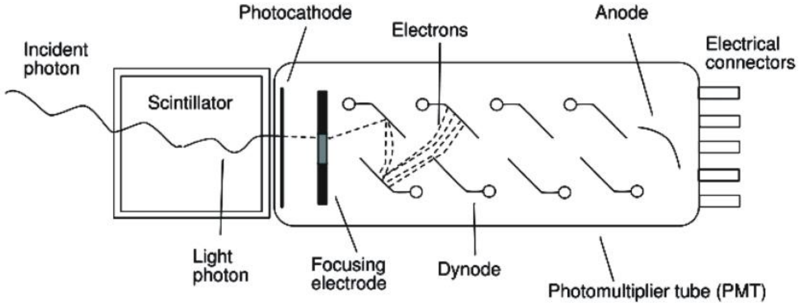
Recorder Circuit

Figure 13, Vacuum-Tubes-013 "Magic-Eye" Tube Typical Circuits

8. Photomultiplier Tubes



Photomultiplier Tube Electronic Symbol



Photomultiplier Tube Construction Diagram

Actual Photomultiplier Tube

Figure 14, Vacuum-Tubes-014 Photomultiplier Tube Electronic Symbol

a. Photomultiplier tubes (photomultipliers or PMTs for short) are extremely sensitive detectors of light in the ultraviolet, visible and near infrared. These detectors multiply the signal produced by incident light by as much as 108, from which single photons can be resolved. The combination of high gain, low noise, high frequency response and large area of collection have meant that these devices still find applications in nuclear and particle physics, astronomy, medical imaging and motion picture film scanning (telecine). Semiconductor devices like avalanche photodiodes have replaced photomultipliers in some applications, but photomultipliers are still used in most cases.

b. Photomultipliers are constructed from a glass vacuum tube which houses a photocathode, several dynodes, and an anode. Incident photons strike the photocathode material which is present as a thin deposit on the entry window of the device, with electrons being produced as a consequence of the photoelectric effect. These electrons are directed by the focusing electrode towards the electron multiplier, where electrons are multiplied by the process of secondary emission.

c. The electron multiplier consists of a number of electrodes, called dynodes. Each dynode is held at a more positive voltage than the previous one. The electrons leave the photocathode, having the energy of the incoming photon. As they move towards the first dynode they are accelerated by the electric field and arrive with much greater energy. On striking the first dynode, more low energy electrons are emitted and these, in turn, are accelerated toward the second dynode. The geometry of the dynode chain is such that a cascade occurs with an ever-increasing number of electrons being produced at each stage. Finally the anode is reached where the accumulation of charge results in a sharp current pulse indicating the arrival of a photon at the photocathode.

d. Photomultiplier tubes typically require 1000 to 2000 volts for proper operation. The most negative voltage is connected to the cathode, and the most positive voltage is connected to the anode. (Negative high voltage supplies are usually preferred.) Voltages are distributed to the dynodes by a resistive voltage divider, though variations such as active designs (with transistors or diodes) are possible. The divider design influences aspects such as the frequency response and rise time, and therefore may be critical to an application.

e. While powered, photomultipliers must be shielded from ambient light to prevent their destruction through overexcitation. If used in a location with high magnetic fields (which will curve electron paths), they are usually shielded by a layer of mu-metal.

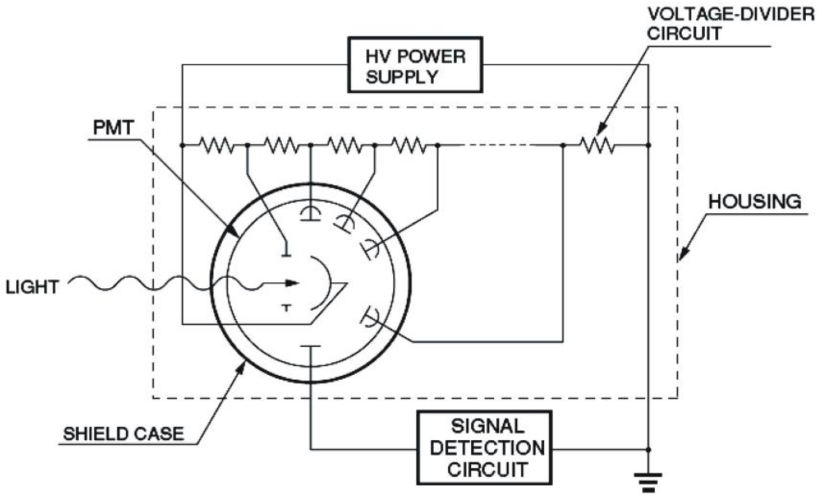
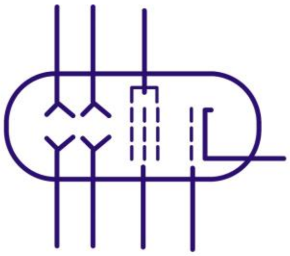
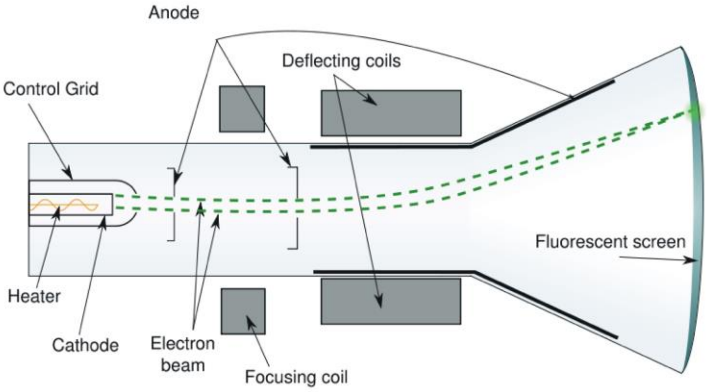


Figure 15, Vacuum-Tubes-015 Photomultiplier Tube Typical Circuit

9. Cathode-Ray Tubes



Cathode-Ray Tube Electronic Symbol



Cathode-Ray Tube Construction Diagram

Actual Cathode-Ray Tube

Figure 16, Vacuum-Tubes-016 Cathode Ray Tube Electronic Symbol

a. The cathode ray tube (CRT), invented by German physicist Karl Ferdinand Braun in 1897, is an evacuated glass envelope containing an electron gun (a source of electrons) and a fluorescent screen, usually with internal or external means to accelerate and deflect the electrons. When electrons strike the fluorescent screen, light is emitted.

b. The electron beam is deflected and modulated in a way which causes it to display an image on the screen. The image may represent electrical waveforms (oscilloscope), pictures (television, computer monitor), echoes of aircraft detected by radar, etc.

c. The single electron beam can be processed in such a way as to display moving pictures in natural colors.

d. The generation of an image on a CRT by deflecting an electron beam requires the use of an evacuated glass envelope which is large, deep, heavy, and relatively fragile. The development of imaging technologies without these disadvantages has caused CRTs to be largely displaced by flat plasma screens, liquid crystal displays, DLP, OLED displays, and other technologies.

e. The inverse process can be used to create an electronic version of an image impinging on a suitable screen in the video camera tube: electrons are emitted by the photoelectric effect; the resulting electrical current can be processed to convey the information, later to be recreated on a CRT or other display.

f. The earliest version of the CRT was a cold-cathode diode, a modification of the Crookes tube with a phosphor-coated screen, sometimes called a Braun tube. The first version to use a hot cathode was developed by John B. Johnson (who gave his name to the term Johnson noise) and Harry

Weiner Weinhart of Western Electric, and became a commercial product in 1922.

g. The cathode rays are now known to be a beam of electrons emitted from a heated cathode inside a vacuum tube and accelerated by a potential difference between this cathode and an anode. The screen is covered with a phosphorescent coating (often transition metals or rare earth elements), which emits visible light when excited by high-energy electrons. The beam is deflected either by a magnetic or an electric field to move the bright dot to the required position on the screen.

h. In television sets and computer monitors the entire front area of the tube is scanned systematically in a fixed pattern called a raster. An image is produced by modulating the intensity of the electron beam with a received video signal (or another signal derived from it). In all CRT TV receivers except some very early models, the beam is deflected by magnetic deflection, a varying magnetic field generated by coils (the magnetic yoke), driven by electronic circuits, around the neck of the tube.

i. The source of the electron beam is the electron gun, which produces a stream of electrons through thermionic emission, and focuses it into a thin beam. The gun is located in the narrow, cylindrical neck at the extreme rear of a CRT and has electrical connecting pins, usually arranged in a circular configuration, extending from its end. These pins provide external connections to the cathode, to various grid elements in the gun used to focus and modulate the beam, and, in electrostatic deflection CRTs, to the deflection plates. Since the CRT is a hot-cathode device, these pins also provide connections to one or more filament heaters within the electron gun. When a CRT is operating, the heaters can often be seen glowing orange through the glass walls of the CRT neck. The need for these heaters to 'warm up' causes a delay between the time that a CRT is first turned on, and the time that a display becomes visible. In older tubes, this could take fifteen seconds or more; modern CRT displays have fast-starting circuits which produce an image within about two seconds, using either briefly increased heater current or elevated cathode voltage. Once the CRT has warmed up, the heaters stay on continuously. The electrodes are often covered with a black layer, a patented process used by all major CRT manufacturers to improve electron density.

j. The electron gun accelerates not only electrons but also ions present in the imperfect vacuum (some of which result from outgassing of the internal tube components). The ions, being much heavier than electrons, are deflected much less by the magnetic or electrostatic fields used to position the electron beam. Ions striking the screen damage it; to prevent this the electron gun can be positioned slightly off the axis of the tube so that the ions strike the side of the CRT instead of the screen. Permanent magnets (the ion trap) deflect the lighter electrons so that they strike the screen. Some very old TV sets without an ion trap show browning of the center of the screen, known as ion burn. The aluminium coating used in later CRTs reduced the need for an ion trap.

k. When electrons strike the poorly-conductive phosphor layer on the glass CRT, it becomes electrically charged, and tends to repel electrons, reducing brightness (this effect is known as "sticking"). To prevent this, the interior side of the phosphor layer can be covered with a layer of aluminium connected to the conductive layer inside the tube, which disposes of this charge. It has the additional advantages of increasing brightness by reflecting towards the viewer light emitted towards the back of the tube, and protecting the phosphor from ion bombardment.

l. For use in an oscilloscope, the design is somewhat different. Rather than tracing out a raster, the electron beam is directly steered along an arbitrary path, while its intensity is kept constant. Usually the beam is deflected horizontally (X) by a varying potential difference between a pair of plates to its left and right, and vertically (Y) by plates above and below, although magnetic deflection is possible. The instantaneous position of the beam will depend upon the X and Y voltages. It is most useful for the horizontal voltage, repeatedly, to increase linearly with time until the beam reaches the edge of the screen, then jump back to its starting value (sawtooth waveform, generated by a timebase). This causes the display to trace out the Y voltage as a function of time. Many oscilloscopes only function in this mode. However it can be useful to display, say, the voltage versus the current in an inductive component with an oscilloscope that allows X-Y input, without using the timebase.

m. The electron gun is always centered in the tube neck; the problem of ion production is either ignored or mitigated by using an aluminized screen.

n. The beam can be moved much more rapidly, and it is easier to make the beam deflection accurately proportional to the applied signal, by using electrostatic deflection as described above instead of magnetic deflection. Magnetic deflection is achieved by passing currents through coils external to the tube; it allows the construction of much shorter tubes for a given screen size. Circuit arrangements are required to approximately linearise the beam position as a function of signal current, and the very wide deflection angles require arrangements to keep the beam focussed (dynamic focussing).

o. In principle either type of deflection can be used for any purpose; but electrostatic deflection is best for oscilloscopes with relatively small screens and high performance requirements, while a television receiver with a large screen and electrostatic deflection would be many meters deep.

p. Some issues must be resolved when using electrostatic deflection. Simple deflection plates appear as a fairly large capacitive load to the deflection amplifiers, requiring large current flows to charge and discharge this capacitance rapidly. Another, more subtle, problem is that when the electrostatic charge switches, electrons which are already part of the way through the deflection plate region will only be partially deflected. This results in the trace on the screen lagging behind a rapid change in signal.

q. Extremely high performance oscilloscopes avoid these problem by subdividing the vertical (and sometimes horizontal) deflection plates into a series of plates along the length of the "deflection" region of the CRT, and electrically joined by a delay line terminated in its characteristic impedance; the timing of the delay line is set to match the velocity of the electrons through the deflection region. In this way, a change of charge "flows along" the deflection plate along with the electrons that it should affect, almost negating its effect on those electrons which are already partially through the region. Consequently the beam as seen on the screen slews almost instantly from the old point to the new point. In addition, because the entire deflection system operates as a matched-impedance load, the problem of driving a large capacitive load is mitigated.

r. It is very common for oscilloscopes to have amplifiers which rapidly chop or swap the beam, blanking the display while switching. This allows the single beam to show as two or more traces, each representing a different input signal. These are properly called multiple-trace (dual trace, quadruple trace, etc.) oscilloscopes.

s. Much rarer is the true dual beam oscilloscope, whose tube contains an electron gun that produces two independent electron beams. Usually, but not always, both beams are deflected horizontally by a single shared pair of plates, while each beam has its own vertical deflection plates. This allows a time-domain display to show two signals simultaneously.

t. Many modern oscilloscope tubes pass the electron beam through an expansion mesh. This mesh acts like a lens for electrons and has the effect of roughly doubling the deflection of the electron beam, allowing the use of a larger faceplate for the same length of tube envelope. The expansion mesh also tends to increase the "spot size" on the screen, but this tradeoff is usually acceptable.

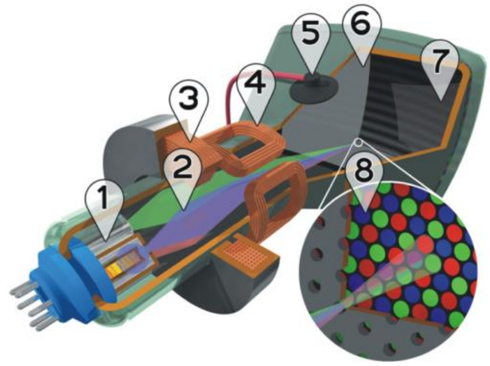
u. When displaying one-shot fast events the electron beam must deflect very quickly, with few electrons impinging on the screen, leading to a faint or invisible display. A simple improvement can be attained by fitting a hood on the screen against which the observer presses his face, excluding extraneous light, but oscilloscope CRTs designed for very fast signals give a brighter display by passing the electron beam through a micro-channel plate just before it reaches the screen. Through the phenomenon of secondary emission this plate multiplies the number of electrons reaching the phosphor screen, giving a brighter display, possibly with a slightly larger spot.

v. The phosphors used in the screens of oscilloscope tubes are different from those used in the screens of other display tubes. Phosphors used for displaying moving pictures should produce an image which fades very rapidly to avoid smearing of new information by the remains of the previous picture; i.e., they should have short persistence. An oscilloscope will often display a trace which repeats unchanged, so longer persistence is not a problem; but it is a definite advantage when viewing a single-shot event, so longer-persistence phosphors are used.

w. An oscilloscope trace can be any color without loss of information, so a phosphor with maximum effective luminosity is usually used. The eye is most sensitive to green: for visual and general-purpose use the P31 phosphor gives a visually bright trace, and also photographs well and is reasonably resistant to burning by the electron beam. For displays meant to be photographed rather than viewed, the blue trace of P11 phosphor gives higher photographic brightness; for extremely slow displays, very-long-persistence phosphors such as P7, which produce a green trace followed by a longer-lasting amber or yellow afterimage, are used.

x. The phosphor screen of most oscilloscope tubes contains a permanently-marked internal graticule, dividing the screen using Cartesian coordinates. This internal graticule allows for the easy measurement of signals with no worries about parallax error. Less expensive oscilloscope tubes may instead have an external graticule of glass or acrylic plastic. Most graticules can be side-illuminated for use in a darkened room.

y. Oscilloscope tubes almost never contain integrated implosion protection (see below). External implosion protection must always be provided, either in the form of an external graticule or, for tubes with an internal graticule, a plain sheet of glass or plastic. The implosion protection shield is often colored to match the light emitted by the phosphor screen; this improves the contrast as seen by the user.



1. Electron Guns
2. Electron Beams
3. Focusing Coils
4. Deflection Coils
5. Anode Connection
6. Mask for separating Beams for Red Green, and Blue Part of Displayed Image
7. Phosphor Layer With Red, Green, and Blue Zones
8 Close-up of the Phosphor Coated Inner Side of the Screen

Figure 17, Vacuum-Tubes-017 Cutaway of TV Picture Tube

Figure 18, Vacuum-Tubes-018 Cathode Ray Tube Electron Gun

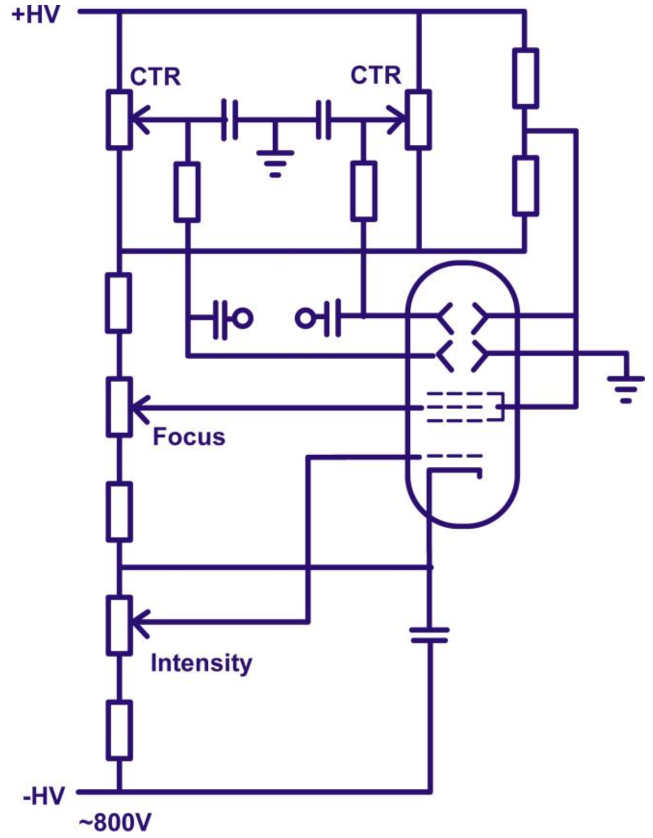


Figure 19, Vacuum-Tubes-019 Cathode Ray Tube Typical Circuit