

Number 51: The OSCILLOSCOPE CRT:
(TechTalk #125)

by: Bob Eckweiler - AF6C

INTRODUCTION:

While writing a three-part article for the *Heathkit of the Month* column on Heathkit's 'O'-series scopes, including their very first kit (the O-1), the section on CRTs got long, so it is presented separately here.

The CRT used in the O-1 through O-4 o'scopes is the 5BP1 (See **figure 1**). The 5 refers to the screen nominal diameter (5 inches); the B is the CRT model sequence; and P1 is the type of phosphor used on the screen. Many 5BP1 CRTs were manufactured for WWII.

The 5BP1 is a **mono-accelerator** CRT. Once the electron beam leaves the electron gun (to be discussed) it travels to the screen with no additional forces working along the CRT axis. Only deflection forces act upon the beam between the electron gun and the screen.

Later CRTs, used by Tektronix, HP and others, have become a lot more sophisticated in design and performance since the forties design, still the basic concepts remain. So here is a look at the 5BP1 and how it works.

Electron Accelerators and Lens:

If you've ever taken a Physics 101 class in college you probably learned that an electron inside a charged sphere has a net force of zero acting on it. All the attraction forces trying to pull it towards or away from the wall cancel, and the electron, if at rest, stays at rest, and if moving continues to move in the direction it was going unaltered by the internal field. The same can be said of a long cylinder except near the open ends where end effects prevail. Thus many CRT elements are cylindrical.

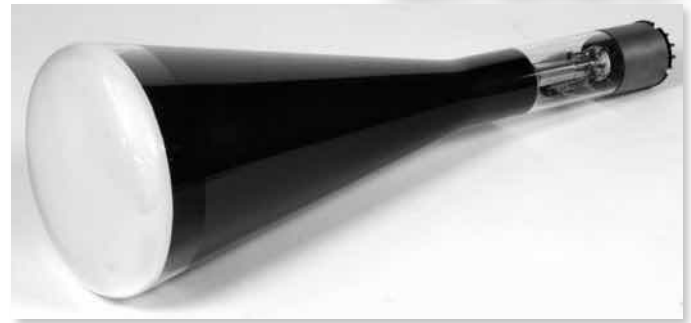


Figure 1: Sylvania 5BP1 Cathode Ray Tube

Figure 2 shows the electric field between two discs. Each disc has a hole in its center to allow an electron beam to pass (blue). If the discs are at different voltages, an electric field is created between the two discs. The dashed lines in figure 2 represent **equipotential lines** of force. Near the center of the disc the field is perpendicular to the axis of the discs and only influence the beam in the direction of the axis. Since the field is increasing in the direction of electron travel the electrons will be accelerated and the electrons coming out the right side will be traveling faster than the electrons entering at the left.

Electrons may be focused by using curved electric fields. These curved fields occur in apertures and bend the electron beam. The equipotential lines may be convex or concave and the voltage gradient may be increasing or decreasing in the direction of electron flow. **Figure 3** shows a convex electron lens with positive gradient that forces parallel or diverging electrons back towards the axis and to a

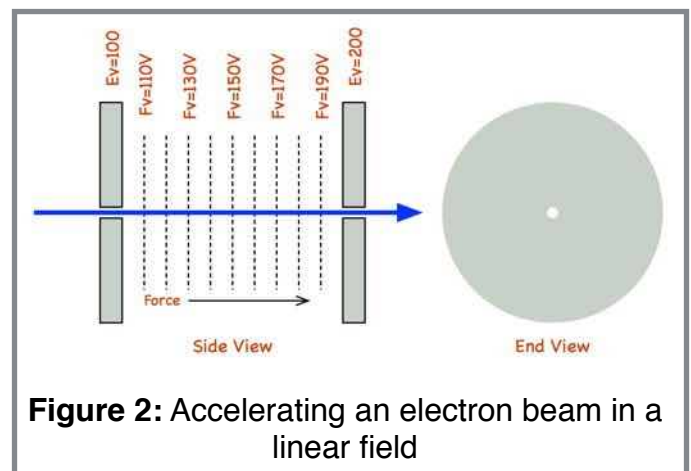


Figure 2: Accelerating an electron beam in a linear field

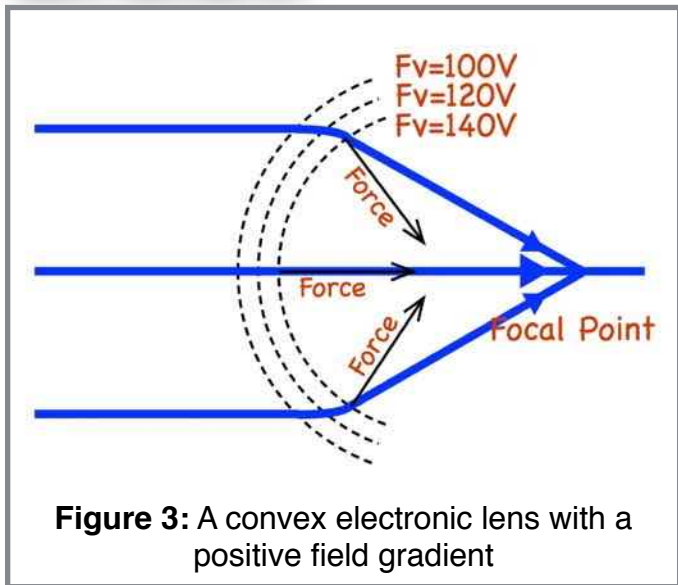


Figure 3: A convex electronic lens with a positive field gradient

focal point. Should the electron lens be concave and the gradient positive, then the electrons not on the axis would be forced to diverge from the axis. By reversing the field gradient, the action of a convex or concave electron lens can be reversed.

The Electron Gun:

The electron gun emits a focused stream of electrons that, when properly adjusted, has a focal point at the phosphorescent screen. The electron gun in the 5BP1 is composed of a heater, cathode, control grid (grid 1), acceleration grid (grid 2), focus anode and acceleration anode. On data sheets these elements are

sometimes referenced with a number, such as “grid 1” or “anode 2”. **Figure 4** depicts the 5BP1 electron gun.

The **heater** is a spiral wound wire coil that fits into a cylinder that is closed at the far end. An oxide coating is on the outside of the end cap. This closed-end tube is the **cathode**. When heated, the oxide coating emits electrons which form a cloud around the cathode. The cathode and heater are closely spaced and since the cathode is commonly at a high negative potential, it is electrically tied to one side of the heater to prevent arcing. This mandates that the heater be supplied by a well insulated separate filament winding on the power transformer.

Surrounding the cathode is the **control grid** (grid 1). The control grid is nothing like the wire mesh grid of a typical vacuum tube; instead it is a cylinder, open at one end but closed at the other, except for a small aperture at the center of the closed end. This grid surrounds the cathode and controls the number of electrons passing through the aperture. The grid should never be positive with respect to the cathode and most intensity controls are wired to prevent this. If the grid becomes negative enough, none of the electrons in the cloud surrounding the hot cathode can pass through. This is the grid cutoff voltage; the screen is dark. As the grid becomes less negative electrons begin to

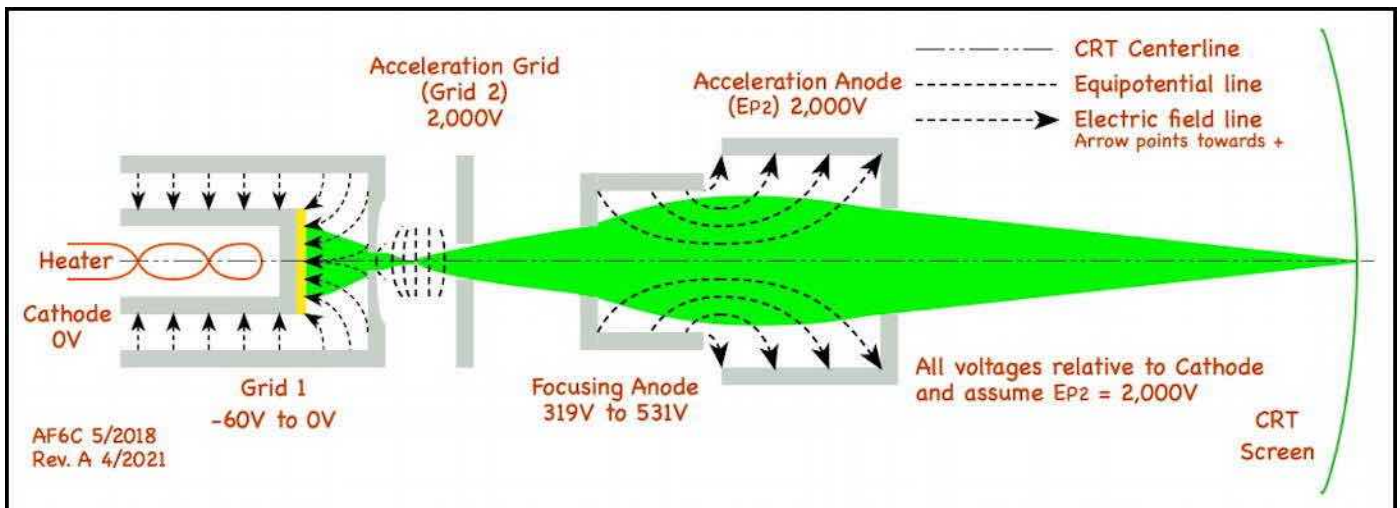


Figure 4: Layout of the 5BP1 Electron Gun

escape through the aperture and are attracted to the accelerating grid. When the electrons first leave the grid aperture they are traveling very slowly. The equipotential lines near the aperture are convex and the slowly moving electrons are deflected towards the center axis. They reach a crossover point near the center of the gap between grid 1 and the acceleration grid.

The **acceleration grid** (grid 2) is a disc with an aperture in its center. In most of the space between two grids the equipotential lines are straight and acceleration occurs in the direction of the axis. As they approach grid 2 the lines become convex and the beam begins to diverge. However by now they are moving fast and the amount of divergence is limited. The potential of the accelerating grid is the same as the accelerating anode; in the 5BP1 they are connected together internally.

In the space between the grid 2 and the **focus-ing anode** the beam passes through another linear equipotential field that slows the electrons down, since the focus anode is at a lower potential than grid 2. The voltage on the focusing anode is adjustable between about 17% and 28% of the accelerating anode voltage by the focus control. The focus anode is cup shaped with a large aperture at its entrance. The larger cup shaped **acceleration anode** immediately follows the focusing anode and the electric field between them bends the diverging electron beam to a focal point. The strength of this field determines where the focal

point occurs and the focus control thus adjusts the dot size on the screen.

Since focus is also determined to some extent by the intensity control, the focus control is on the front panel so focus can readily be adjusted as needed. It is not a set and forget control.

The Cathode Ray Tube Screen:

The screen of the CRT contains a phosphorescent coating that emits light when excited by bombarding electrons. Different phosphors have been developed for different display purposes. Two important aspects of a phosphor are its color and its persistence. Persistence is how long the spot remains on the screen after electron bombardment has stopped at the location. Short persistence is usually used for photo oscillographs, medium persistence for television and oscilloscopes, and long persistence for radar. Table I lists the phosphors used in Heathkit products. Of special interest is the P7 phosphor used in the SB-620 spectrum analyzers. It has two colors and two persistences, a short-medium purple-blue fluorescence and a long yellow-green phosphorescence. By using a color filter after the screen either color can be selected.

Trace Deflection:

Without a way to move the spot around the screen, the CRT would be useless. Deflection may be introduced by two means, **electromagnetic** and **electrostatic**. Electromagnetic, commonly used with TV picture tubes, is accomplished by an external pair of coils called a yoke. Electrostatic deflection occurs internally by two sets of parallel deflection plates mounted 90° from each other. One set of plates is located closer to the screen than the other. This is usually the vertical deflection plate set. After leaving the electron gun, the beam of electrons passes between these two sets of deflecting plates causing the beam to deflect away from the center of the screen. **(Figure 5)** The voltage on the deflecting plates consists of the sum of the desired signal or sweep voltage and a DC bias voltage that is set by the appro-

COMMON* CRT PHOSPHORS			
Type:	Persistence	Color	Use
P1	medium	green	gen'l o'scopes
P2	medium	blu/grn	o'scopes, radar
P4	33 ms for TV	white	BW TV display
P7	short to med.	blue	radar and spec-
	and long	yellow	trum analyzers
P11	short to med.	blue	o'scopes & photo
			oscillographs

* As used in the field of amateur radio

Table I

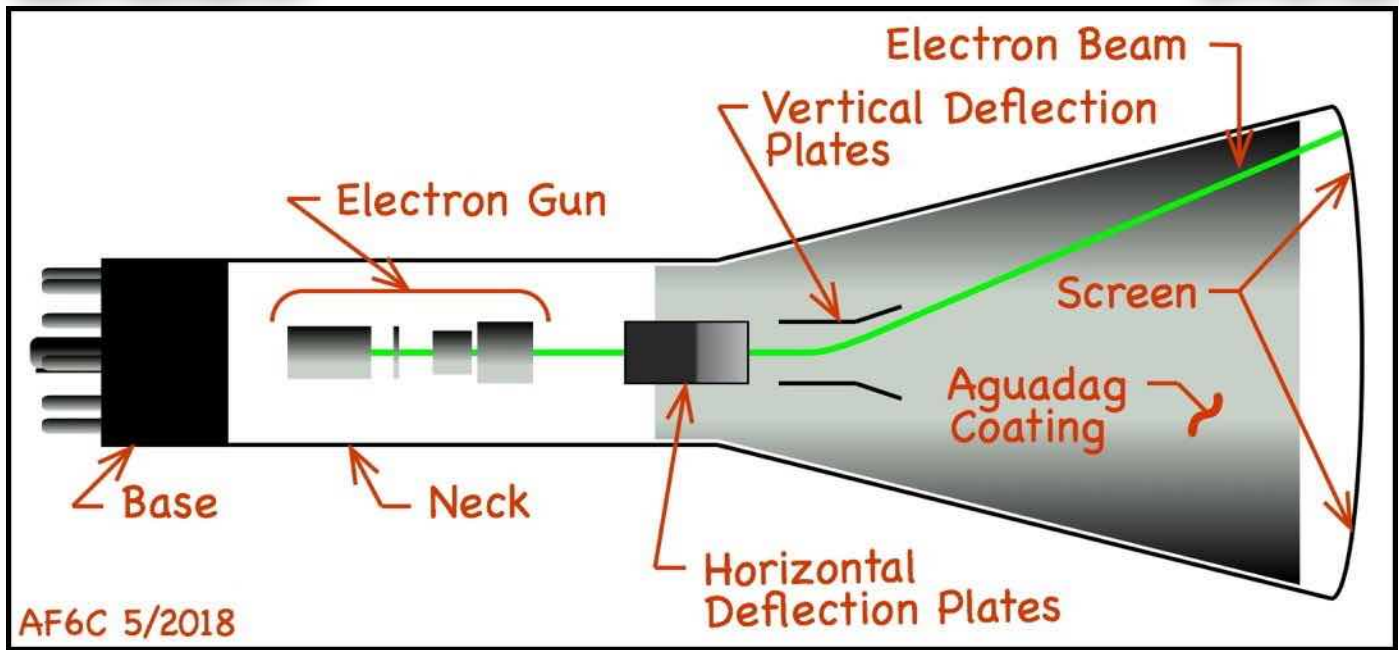


Figure 5: Inside View of the 5BP1 CRT

appropriate (vertical or horizontal) position control. The deflection voltage required to move the trace a given distance is specified in the data sheet as volts-per-inch of deflection per-kilovolt of accelerating potential. Since the distance from the vertical plates to the screen is less than the horizontal plates, its deflection voltage is typically higher. For the 5BP1 the vertical deflection voltage is specified at 35 to 49 volts per inch per KW, and the horizontal deflection voltage is specified at 31.5 to 44.5 volts per inch per KW (of the anode 2 voltage). The deflection plates usually have a single flare bend in them to widen the gap at the exit end and allow wider deflection with the plates closer together.

Aquadag Coating:

The inside of the CRT bulb, from near the end of the neck to just short of the screen, is painted with aquadag, a conducting colloidal graphite coating. When electrons collide with the screen they often knock electrons off the screen, resulting in secondary emission similar to what happens in a tetrode vacuum tube. These electrons, if they are allowed to accumulate, can form a negatively charged cloud between the beam and the screen that inflicts forces on the beam causing distortion. The coating is at the anode 2 voltage and attracts these slow moving electrons, capturing them.

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Post Deflection Acceleration (PDA):

The 5BP1 is a mono accelerator CRT. Heath used mono CRTs in most of their early scopes. The exception is the Heathkit O-8 o'scope that uses the 5CP1 CRT. This CRT has an additional accelerator element after the deflection plates. The advantage is that the electrons pass the plates at a lower velocity and thus deflection may be done with a lower voltage. The electrons are then accelerated further towards the screen. The 5CP1 maximum PDA (anode 3) voltage is 4 KV. TV picture tubes use a PDA voltage of 15 to 30+ KV.

PDA CRTs generally are brighter than mono accelerator CRTs, however that is only an advantage at high frequencies; much higher than the fastest 'O' series Heathkit scope can achieve. At lower frequencies mono acceleration CRTs are quite bright.

Astigmatism:

The dot on the face of a CRT can be in focus in one axis and somewhat out of focus in the other. Astigmatism may be corrected by adjusting the voltage on the anode 2. This changes the electron lens that forms between that anode and the first set of deflection plates, slightly varying the focus in one axis and not the other. In the Heathkit O-1 through O-5 no astigma-

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tism control is incorporated. In the O-6 a fixed resistor is used to provide a fixed correction, and in the O-7 through O-12 an astigmatism control (called Spot Shape) is incorporated as an internal adjustment.

CRT Voltages:

Figure 4 shows the voltages with respect to the CRT Cathode. However, CRT voltages are high and electrode spacing is close, thus certain maximum voltages are specified between various electrodes. One is the peak voltage between the anode 2 (acceleration anode) and any deflection electrode. For the 5BP1 that voltage is 500 volts maximum. Since the 5BP1 can operate with 2KV on anode 2 this makes the DC potential required on the plates excessive.

The solution is simple. Start with the grid 1 at a high negative voltage and with the anode 2 at ground potential or a few hundred volts positive. The cathode and focus anode voltages may then be tapped off a resistor chain between the negative high voltage supply and ground. **Figure 6** shows a typical resistor chain and includes an optional astigmatism control.

Summary:

As LED and OLED screens continue to take over the display market, CRTs are quickly becoming an item of historic curiosity. Still, the idea of "seeing" what is happening in an electronic circuit makes the oscilloscope a most valuable test instrument. A good DC coupled o'scope can measure voltage, frequency and detect glitches that would never be visible with even the most modern digital voltmeter. Today's o'scopes use digital display screens and get rid of the need for a fragile and expensive CRT, and high voltage power supply needed to accelerate the electrons in the CRT.

If you want to learn more about Cathode Ray Tube technology a good source is "[Cathode Ray Tubes](#)", by Chuck DeVere. The book is part of the *Tektronix Circuit Concepts* library (second edition, fourth printing 1969). It is available on the web.

The WWII Surplus CRT:

It was the stockpile of CRTs that was available surplus after WWII that started a whole new industry in electronics. Just how inexpensive the 5BP1 CRT was to companies that bought them in bulk is unknown. To get some idea I pursued a few 1946 through 1948 issues of *Radio News* and found the two lowest-price ads for the 5BP1 CRT (See **Figures 7** and **8**).

Shortly after the end of the war an ad was selling the 5BP4 for \$18 each in the January 1946 issue. War surplus electronics were slowly ap-

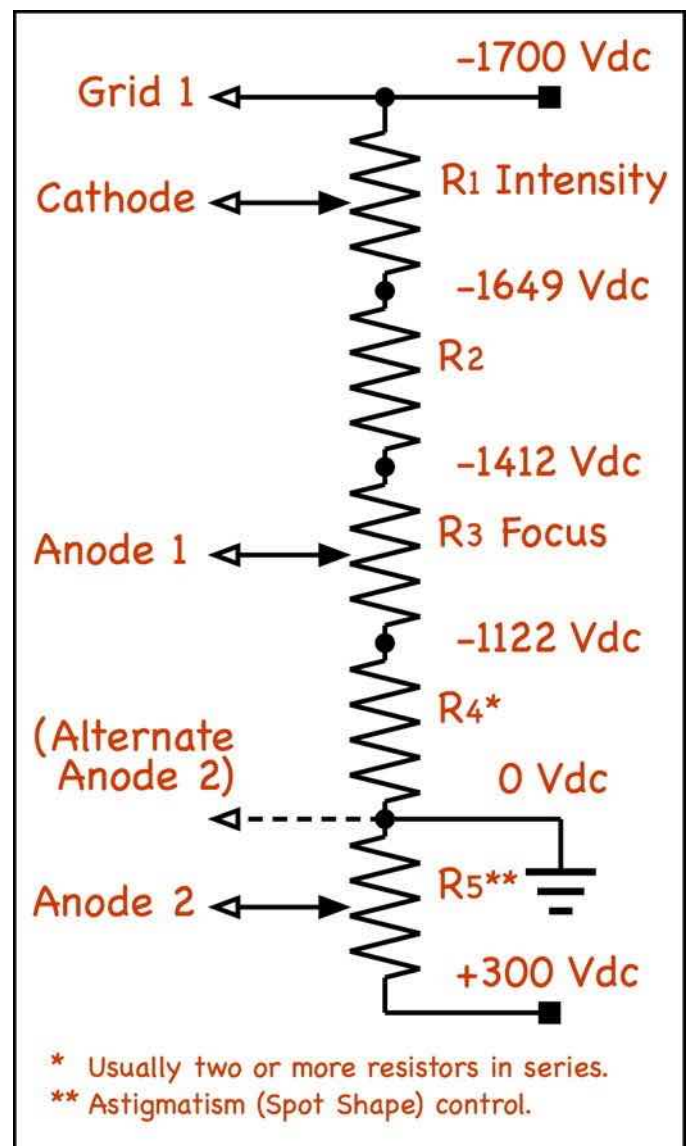


Figure 6: Typical CRT resistor divider chain designed to prevent high anode 2 voltages. Left pointing arrows go to CRT connections.

pearing at the time. A year later (January 1947) TAB in New York City offered the 5BP1 for \$9.95 with the 11-pin (medium magnal) socket thrown in. Another year later (January 1948) the TAB ad had the 5BP1, 5BP4 or 5CP1 for \$2.25 each. The socket was 59¢ additional. By April of 1948 the TAB price had increased to \$3.75. In August of 1948 when the Lafayette and Photon ads appeared, the TAB ad did not advertise any CRTs. Also in the August issue G & G Radio Parts on Vesey St. was selling 5BP1 CRTs in lots of 4 for \$1.79 each as "new and in original cartons". Both TAB and G & G were located in New York City's "Radio Row". (See RF for May 2004 page 6 for more on Radio Row.)

The two ads shown on this page represent the lowest prices that could be found after moderate searching. The Photon ad ran for many month with the \$1.15 price, even though a typo in the early ads call it the 5PB1.

Looking at the low prices for a single CRT one has to believe Heath probably purchased the CRTs for significantly less than a dollar each, perhaps less than 50¢ each. How many 7" x 7" x 18" boxes can you get in a railroad box car?

The Heathkit article covering the O-1 through O-4 has been completed and published in the June issue of "RF" Newsletter. It will be available on the [Heathkit of the Month](#) webpage sometime in the next month.

73, from AF6C



TUBE SPECIALS			
5BP1	.....\$1.15	726	..... 4.95
3AP1	..... 2.25	75TL	..... 2.50
2X2	..... .75	5BP4	..... 2.50
9002	..... .75	717-A	..... .69
		6L6G	..... 1.10
		12A6	..... .29
		4 for	.. 1.00
		VR150	..... .90

PHOTOCON SALES
1062 North Allen Avenue Pasadena 7, Calif.

Figure 7: Ad from the August 1948 issue of *Radio News* showing the lowest 5BP1 price found. Photocon kept this price over many ads.

Spot-lite Values

XPS916-
5BP1 Tube While
They Last
Your Cost **\$1.39**

5BP1/5GP1 C-R Tubes
Brand new 5BP1/5GP1 cathode ray tubes, perfect for oscillograph use. Green fluorescence with medium persistence. Five inch screen, medium shell magnal 11 pin base, 6-3 volt heater, 2500 volts on anode No. 2. Each tube individually boxed. About one-tenth list price. Quantity extremely limited.

from *Lafayette*

MAIL NOW

New York
100 SIXTH AVE.
110 Federal St., Boston 10
24 Central Ave., Newark 2

Lafayette Radio
RADIO WIRE TELEVISION, INC.
Dept. RH-8, 100 Sixth Ave., N. Y. 12

Figure 8: Another ad from the August 1948 issue of *Radio News* showing another low 5BP1 price.

This article is based on the TechTalk article that originally appeared in the May 2018 issue of RF, the newsletter of the Orange County Amateur Radio Club - W6ZE.

REVISIONS

Rev. A. 4/16/2021:

1. Repaired some typos and a repeated word.
2. 'Acceleration Grid' and 'Grid 2' were used arbitrarily in certain places. They are the same grid. Corrected the text and 4 to reflect this.
3. The Heathkit HO-13 uses a 3RP1 CRT, not a 3RP7 as stated. The SB-620 does use the 3RP7 CRT.