COLOR MONITOR THEORY
FOR THE TANDY 2ØØØ

The Tandy CM-1 Color Monitor for the Tandy 2ØØØ Computer is a special purpose, high performance, high resolution color monitor. It is capable of displaying up to 64Ø horizontal dots in up to 4ØØ rows. Each dot may be one of 15 colors, including black.

The CM-1 requires six signals from the computer:

Horizontal sync (HS)- TTL level, negative going
Vertical sync (VS)- TTL level, negative going
Red drive (R)- TTL level, positive going (1 = ON)
Green drive (G)- TTL level, positive going (1 = ON)
Blue drive (B)- TTL level, positive going (1 = ON)
Intensity (I)- TTL level, positive going (1 = active)

The CM-1 also requires a source of 12Ø volts AC at 6Ø Hz to provide primary power supply voltages.

Despite it somewhat strange signal requirements, the CM-1 is only slightly different from a standard color television receiver. Of course, since the CM-1 does not receive any television stations it will need no receiver section, no IF strip, and no video demodulator. It is incapable of producing sound, so no audio section is necessary. Since the CM-1 accepts each input directly it contains no color demodulators, color, killer, or sync separator. With all of this gone, the CM-12 can concentrate on doing is job -- producing tiny colored dots.

Before trying to understand the circuits of the CM-1 we need to understand why they must perform as they do. We know WHAT they do -- produce tiny colored dots. But WHY they MUST perform in such a strict manner is called GENERAL COLOR THEORY.

The science of determining and describing colors is known as COLORIMETRY. Colorimetry concerns itself with hue, brightness, and saturation. HUE is the actual color of the picture or dot. In the CM-1 the BRIGHT RED and DARK RED dots both have the same hue -- RED.

The difference in these two dots is their relative BRIGHTNESS. The bright red dot is brighter than the dark red dot. We'll see later that this is actually due to the amount of electrons striking the screen.

SATURATION is something that we really don't have to worry about in the CM-1. A vivid red, like the bright red dots on the CM-1, have no white mixed with them. They are RED, pure and simple. In color televisions, though, most colors have some amount of white mixed in with them, diluting them, making them less brilliant. These colors are known as PASTELS. The CM-1 is designed to produce "pure", vivid colors with no white mixed in. In fact, pastels colors on the CM-1 may be an indication of a misadjusted set.

In nature, we know that "white" light is actually made up of a mixture of all visible colors. You have probably played with a prism, and we have all seen rainbows. Both demonstrate the mixed colors of white light. This band of colors produced when light is "disassembled" is called its SPECTRUM.

The visible color of an object is based on its ability to absorb or reflect different portions of the light spectrum. The red stripes on the American flag reflect RED and absorb all other colors. The white stripes reflect almost all of the spectrum they receive.

If you payed any attention at all in your elementary art classes you will remember that an artist works with three primary colors - RED, BLUE, and YELLOW. By mixing these three colors in different quantities, he can make any color he desires. Actually, what he is doing is making a mixture of pigments that selectively absorbs and reflects portions of the light spectrum, the end result being the particular shade the he desired. This process of absorbing unwanted color is called SUBTRACTIVE COLOR MIXING.

Televisions and monitors do not absorb or reflect light. By using the photoelectric properties of certain natural elements, the monitor produces light. A controlled beam of electrons is projected at fixed layer of atoms known as the PHOSPHOR. When this electron beam collides with the phosphor some electrons in the atoms are knocked out of place. Each electron being knocked out of place produces a PHOTON of light. As a group, these electron collisions are random, producing WHITE light.

The CATHODE RAY TUBE is responsible for producing and controlling the electron beam, and for supplying the layer of atoms to be bombarded. All other circuitry inside the television or monitor, with the exception of the sound circuits, is designed to have some effect on the CRT. The CRT becomes the main component of a television or monitor. A good level of understanding of the CRT will help you understand the monitor in general.

The Cathode Ray Tube (CRT) is a highly specialized form of vacuum tube. It has all the characteristics of a vacuum tube, but serves a highly specialized purpose. The basic CRT has six basic parts:

FACEPLATE
PHOSPHOR - "painted" on the inside of the face plate
ELECTRON "GUN" - produces the electron beam
PLUG - connections for the voltages to go into the tube
GRIDS - for focus and brightness control
BODY - the glass container that holds everything else

There are, of course, several other parts necessary to control the CRT, but are not actually part of the CRT. These include the YOKE, used to steer or deflect the electron beam, and the HIGH VOLTAGE LEAD. There should also be a strong, protective, clear WINDOW over the face plate to protect the user should the CRT physically break.

To see the action of the CRT, we start with the electron GUN, whose job it is to produce a beam of electrons to strike the phosphor coating on the faceplate. The gun must first produce the electrons. There are several methods for doing this, each having its own purpose. Of these, the INDIRECT HEATER method is the most common and is the one used in the CRT. The HEATER is the glowing wire seen inside the end of an operating tube. It is supplied with a source of voltage (usually, but not always, an AC signal). Near to, but not touching, the heater is the CATHODE. The cathode is made of a special material designed to give emit electrons as it is heated. As the heater becomes hot the cathode is also heated, and electrons are "boiled" off. The cathode is constructed in such a manner that the electrons are emitted in a small beam at the end of the cathode.

In most cases the amount of electrons is controlled by varying the electric potential between the cathode and the GRIDS. It is quite common to find the video signal applied to the cathode of the CRT. If we study this configuration we will see that it is actually a COMMON GRID circuit, similar in effect to the COMMON BASE transistor circuit. By varying the potential on the cathode we can control the amount of electrons released to form the beam.

Actually what we are varying is the potential between the cathode and the CONTROL GRID. Physically, the control grid is very close to the cathode. This means that a relatively small potential between the cathode and the control grid can control the electron beam just as well as a large potential on a grid farther away.

In the CM-1 the control grid is at ground potential. To control the flow of electrons we must make the control grid more negative than the cathode. This will repel or reflect the electrons back to cathode. If we make the control grid negative enough the electron beam will be completely cut off.

But the control grid is at a fixed ground potential. To make the control grid negative with respect to the cathode, we must make the cathode positive. This is done the biasing circuits contained in the monitor. Now, if we supply a video signal to the cathode to vary it more or less positive, we can control the electon beam in this manner.

By themselves the electrons do not have enough energy to reach the phosphors. They would "die out" well before reaching the faceplate. To prevent this we use a ACCELERATION or SCREEN GRID. By supplying this grid with a rather high voltage the electrons are attracted to the grid. The pick up a great deal of speed in the process, enough to insure that they will reach the phosphor. While the electrons are attracted to the acceleration grid, they pick up enough speed that most of them overshoot the grid and travel on to the phosphor.

We now have a true electron beam, but it is still rather random. For fine details we need the electrons to hit the phosphor in a very small, controlled spot. We do this with the FOCUS grid. The focus grid appears rather like a small tube inside the CRT neck, but it is actually an electromagnetic lens. By controlling the voltage on the focus grid we can focus the electron beam into a very tiny, bright spot.

We now have a tiny, focused electron beam. What do we do with it? To produce a useable picture we must SWEEP the beam across the face of the CRT in both a vertical and horizontal predictable manner. This is the job of the SWEEP circuits inside the monitor. Since the electron beam has an electrical charge it can be controlled by an electromagnetic field. The sweep circuits produce such a field in the YOKE. The yoke is actually a large coil of wire fastened to the neck of the CRT. There are actually four coils of wire in a yoke, two each for the horizontal and vertical.

It is the job of the PHOSPHOR to actually produce the light. PHOSPHOR is a generic name for a class of chemicals that produce light when bombarded with an electron beam. The color of the light produced is a function of the phosphor used. The amount of light produced is also a function of the phosphor, but is mainly controlled by the power of the electron beam. If no electrons strike the phosphor the face is dark. If many, many electrons strike the phosphor the face is light. The video signal and control grid determine how many electrons actually strike the phosphor and produce varying amounts of light.

The phosphor does not stop producing light immediately when the electron beam stops. This is known as PERSISTANCE. Phosphors can be designed for varying persistance factors. The phosphors used in television tend to have very short persistance factors to allow rapid changes in brightness that occur during a television show. Computer monitors are generally medium length phosphors, since each dot produced has relatively little energy. This means the dot will continue to glow after the beam has passed, and may continue until the dot is again lit on the next sweep. Devices like some oscilloscopes have relatively long persistance phosphors to keep the display bright even when it is not being scanned.

What we have just covered is the basic theory behind a black-and-white television or computer monitor. An electron beam is produced, focused, and steered towards a phosphor coating on the faceplate of the CRT. The color monitor is only slight different. The major differences are in the CRT and the changes to the support circuitry to control the CRT.

While the black and white CRT has one electron gun, the color CRT has three. While the faceplate on the black and white CRT has one phosphor the color CRT has three. To separate these three phosphors the color CRT has a SHADOW MASK, the black and white CRT has none.

Why does the color CRT have three phosphors and guns? We step back slightly to our elementary art class for this. We discussed that the artist has three primary colors to work with - red, yellow, and blue. He mixes all other colors using subtractive mixing.

However, the color CRT is is a light SOURCE. It does not absorb or reflect colors, but actually produces a colored spot of light. we can not use subtractive mixing. We must use ADDITIVE MIXING. To do this we need a slightly different set of colors. The color CRT uses RED, GREEN, and BLUE. By turning on the red, green, or blue dots with varying brightness on each dot we can produce all the colors necessary.

We mentioned that the color CRT facemask contains three phosphors. These phosphors are produced such that one will produce GREEN light, one will produce RED light, and the third will produce BLUE. The facemask is very carefully constructed so that any one dot on the screen will contain only one spot of each phosphor. These spots may be arranged vertically, horizontally, or triangularly, but there is only one spot for each dot.

These phosphor dots are very small, in many cases smaller than the electron beam striking them. To prevent an electron beam from striking two phosphor dots at once we need a SHADOW MASK. This mask is actually a screen of very tiny holes. It is very carefully aligned such that the electron beam stoped from striking other phosphor dots. It leaves a shadow in these areas, striking only the proper color phosphor.

Since there are three separate phosphors, there are three separate electron guns. Each gun is responsible for striking only one color of phosphor dot. This means that we have a red gun, a green gun, and a blue gun. All three guns are controlled by the same sweep circuits, so if the CRT is properly aligned and manufactured each gun will strike the same display dot at the same time, but each gun will strike only its proper color within that display dot.

Making sure that each gun strikes the same dot at the same time, but strikes only its own color is called CONVERGENCE. We would like to be able to adjust the set so that EVERY dot is properly converged, but in reality this is impossible. We can only adjust and juggle until the best possible convergence is obtained. The edges may be off slightly. This is acceptable.

A misconverged monitor can be seen by having the computer draw vertical and horizontal WHITE lines. A misconverged set will display these lines as two or three colored lines. The convergence procedure given in the service manual should be completed, more than once if necessary, until the lines all "converge" into solid white lines.

We have determined that the color displayed on a color monitor is a function of ADDITIVE MIXING of the three phosphor dots. What colors can we get from a color monitor? Since the color monitor is basically just a "stripped down" color television, we should be able to get all the colors available to a color television. However, the final colors available is determined by the computer, and in the case of the CM-1 the monitor itself.

The CM-1 is designed to accept TTL (Transistor-Transistor Logic) level inputs. These signals are used to control the three color guns. TTL level signals are digital, 1/Ø, ON/OFF. This means that any of the three guns can be only ON or OFF. We can not provides "shades" of colors since no gun can be "half on" or "half off". with three guns we can have eight (2^3) possibilities:

ALL GUNS OFF	RED ONLY ON	GREEN ONLY ON	BLUE ONLY ON
RED AND GREEN ON	RED AND BLUE ON	BLUE AND GREEN ON	ALL GUNS ON

Since the dots use additive mixing the following colors are available:

BLACK	RED	GREEN	BLUE
YELLOW	MAGENTA	CYAN	WHITE

Since the color guns signals are digital the secondary colors (yellow, magenta, cyan) should be an equal mixture of the two involved guns. However, the three phosphors are not equally powerful. The green phosphor is less sensitive than the red or blue. We use the green phosphor as a reference and adjust the red and blue signal amplitude to match. This process is known as PURITY. This adjustment makes sure that the light produced by the three phosphors is equal so that "pure" colors are produced.

One last signal is used by the CM-1. This is the "I", or INTENSITY, signal. This signal is used to change the amplitude of the reg, green, and blue signals going to the guns. If the I signal is LOW the RGB signals are of less amplitude and the colors are dimmer. If the I signal is HIGH the RGB signals are full amplitude and the colors are brighter. Using the I signal gives us another color set:

BLACK	DARK RED	DARK GREEN	DARK BLUE
DARK YELLOW	DARK MAGENTA	DARK CYAN	GRAY

In all, the CM-1 is capable of producing 15 colors.