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# FUNDAMENTALS OF THE CATHODE RAY TUBE BASED DISPLAY AND ITS MAINTENANCE AND CONSERVATION WITHIN CONTEMPORARY ARTWORKS

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This paper will analyze the fundamental construction of the cathode ray tube (CRT), its basic functioning as well as how CRTs age over time, outlining their specific signs of deterioration and malfunction. Possibilities for the conservation, replacement, or both, of CRTs and CRT-based displays on a long-term basis will be examined, while considering market options and availability as well as the best estimates for the CRT's life span. Also to be discussed are current possibilities in terms of refurbishment and the options for migration from CRT based display towards new technologies. The specific elements related to the build of the CRT that one should look for when considering a migration will be analyzed. Finally, the optimal conditions for conservation of CRT devices that are still in use or held in museums and private collections as back-ups planned for the restoration of art works will be presented.

## FUNDAMENTAL CONSTRUCTION OF A CRT

Here are some basic descriptions of how a CRT is composed and functions: A CRT display-unit is composed usually of an outer case and, inside the case, an array of components of which the main part is a glass tube called a Cathode Ray Tube (CRT) and electronic circuit boards which drive the CRT, providing power and signal. The

CRT is composed of a cathode and an anode. The front internal glass is a phosphor-coated screen. The neck of the CRT tube is wrapped in coils of wires.

The following are some details to help understand the relationship between the phosphor coating and the coils visible on the neck: The terms anode and cathode are used in electronics as synonyms for positive and negative terminals. For example, one could refer to the positive terminal of a battery as the anode and the negative terminal as the cathode. In a cathode ray tube, the "cathode" is a heated filament, not unlike the filament in a normal light bulb. The heated filament is in a vacuum created inside a glass "tube." The "ray" is a stream of electrons that naturally pour off a heated cathode into the vacuum. As electrons are negative and the anode positive, it attracts the electrons pouring off the cathode. In a cathode ray tube, the stream of electrons is focused, by a focusing anode, into a tight beam and then accelerated by an accelerating anode. This tight, high-speed beam of electrons flies through the vacuum in the tube and hits the flat phosphor coated screen at the other end of the tube. The phosphor is arranged in dots, which glow when struck by the beam. In a color CRT, the phosphor dots are grouped together in threes, with one phosphor dot that is red, one that is green and one that is blue. The three dots combine together to make one point of light, or pixel, that you see on the screen. The signal input tells the unit what color each pixel should be and how bright it should shine. The cathode or "electron gun" shoots out three electron beams. The beams aim at one pixel on the screen at a time. One beam will hit the green phosphor dot, one will hit the red dot and one will hit the blue dot of the pixel. Back toward the narrow end of CRT, there are steering coils made of copper windings, which are wrapped around the neck of the tube. These coils, through an electrical input, are able to create magnetic fields inside the tube, and the electron beam responds to the fields. One set of coils creates a magnetic field that moves the electron beam vertically, while another set moves the beam horizontally. By controlling the current in the coils, the electron beams can be positioned at any point on the screen. In the case of a black and white CRT display, the same principles apply except that a single electron beam is projected from the cathode, the phosphor coating is monochromatic, and shades of gray are generated through the brightness circuit triggered by the originating signal. Depending on the model the image scanning or creation of the image on the screen occurs at different speeds. The circuit boards driving the CRTs have evolved dramatically since their creation going from vacuum tube based circuitry, to solid-state capacitors, advanced printed circuit boards and to IC chip driven circuitry.

## STORAGE

An important question for museums with CRTs in their collections is the best way for them to be stored. CRTs are vacuum devices therefore the phosphor screen and cathode have minimal change during storage. The rated storage temperature for a CRT is -10°C to +65°C. The storage room humidity level should be kept below 80% (because of the metal in the electron gun or pin and related circuit boards) and any storage should never allow condensation on any of the parts. The main concern for long-term storage is the potential for parts to rust as humidity levels increase. For storage and handling of a loose CRT that has been extracted from its case, or purchased unassembled to any electronic parts, the CRT should be sealed in plastic to keep any potential humidity away. The tube should be stored in normal position for viewing. It should not be stored face down in case any loose internal particles might collect on the face and create black spots on the phosphor. Special care should be taken to protect the neck of the CRT against potential shocks and breakage during handling. A unit still fully assembled, including manufacturer's case, should be wrapped in plastic and conserved under the same guidelines as above. Once it is removed from storage make sure there is no sudden temperature change, such as, going from air-conditioned room to a non air-conditioned room, as these different room temperatures will

generate water condensation on the circuit board on a microscopic level which could cause damage. Because a CRT tube is under vacuum it should operate as well 20 years from now as it does today as long as humidity levels are low where it is stored. After storage it may have a slow emission rise (slowly coming to full brightness). A standard technique is to run the unit from 24 hours up to a week to "age-in" the CRT and get it back to an optimal performance level. Any given unit in operation is normally warranted for 10,000 hours or 12 months - whichever comes first. CRT displays stored for a long period of time can have component degradation even in optimal settings. The rate of decline depends, in good conditions, generally upon the quality of components and overall usage. As a CRT advances in long-term use, without rest time, the degradation rate can increase due to the cathode loosing the ability to generate electrons.

Basic turn-on procedures after long-term storage are to first do a physical examination first for dust, or any other signs of impact, rust or problems including odors or malfunctioning control dials. Plug the unit in without powering it on, wait 20 minutes so that any internal parts that require it can be charged. Then turn on the device using the manual "power on" button and do a smell check and front face check. Plug in a video signal to the input, preferably a test pattern color bar and then run for 24 hours under supervision. In advance of a planned exhibition a 2 week full day run and on-off testing is recommended following the same daily schedule as is planned for the art work or unit during exhibition.

General safety precautions when working with the internal parts of CRT display are multiple and only trained specialists should handle these. The most critical thing to know, as a brief overview, is that since the CRT tube is under vacuum, any puncturing or breakage of the tube can cause an implosion which can be very hazardous. In addition high voltage is stored inside the tube so it must be discharged before handling. Black and white devices hold about 10,000 volts, with low current, whereas color devices hold between 10,000 to 40,000 volts, also with low current,; these voltages increase based on the size of the tube. Some of the capacitors on the circuit boards can also hold charge.

## SIGNS OF DETERIORATION AND MALFUNCTION

Some of the basic signs of aging of a CRT tube are as follows: loss of image focus or loss of image sharpness, overall darkened picture, discoloration, general yellowish or reddish hue (loss of white and blue hue), image purity problems ( discoloration of image in certain areas of the screen), phosphor burn (irreversible image birn into the screen phosphor), slow warm-up time during initial turn on before full brightness is achieved. Electrically one can have flickering, vertical hold problems (image rolling top to bottom on the screen, failing to hold still) and image banding, all of which would be due to faulty circuitry. If a device has been in operation for extensive periods (hours use) there is no permanent way to revive it. The cathode material in the electron gun is already used up. If a device is unused and appears weak upon initial operation it could just be a matter of an "under-aged" gun which at one time could be corrected by rejuvenating via refurbishing firms but those businesses have closed in the last 5 years so this is no longer an option. The only option is to attempt to age-in the CRT by running the device as previously mentioned.

Once signs of deterioration begin to appear the course of actions to take, with the help of an experienced technician, are the following: source the service manual for the exact model in question, check circuit board, check CRT. Some solutions to problems may include, for older devices, installing image boosters, which can shorten the life span of CRT but can provide a more satisfactory image for the short term; for all models, cleaning the circuitry and the CRT may help extend their life; increasing brightness via internal control dials, which can increase image quality but will shorten the lifespan of the CRT as well.

If no solution can be found with the existing original parts, few options are available. The first step is to seek a back-up or replacement unit. A back-up is, in most cases, is a matching (same model) CRT and circuit board in working condition, preferably new, assembled or in parts. If this is not available the following solutions are suggested:

- Find a comparable size model with similar external aspect and correct operational features. Replace original unit with back-up unit within the artwork.
- Find same size CRT of a different model with compatible operational features. Extract internal parts from both original and back-up cases. Insert within the original case the back-up non-matching model's internal electronics. Secure and test. Store original parts in archival boxes or secured in an acrylic casing.
- If a back-up CRT has been sourced with associated electronic parts which cannot fit within an original case, extract all original parts from original case, insert a replacement CRT and run CRT power and video controls (cables) via remote circuitry at a maximum recommended distance of 10 feet. This option requires advanced electronic engineering and extensive testing.
- Replace original CRT and circuit boards with an alternate technology, such as a Liquid Crystal Diode (LCD) flat screen of comparable size.

## MARKET AVAILABILITY

CRT devices that have been manufactured before 1990 usually are very difficult to source new or used. Any unit that is sourced must be tested once received. Depending on the quantities and sizes sought the task of finding exact models can go from difficult to impossible. The smaller the CRT is, the earlier it has gone out of production, starting with the 5 in. and upwards in size. From the early 90's smaller units such as the 5 in. became reserved for specialty monitors in use in security and broadcast television studios, both stationary and mobile and in public settings such as buses and used for applications such as for medical equipment and the military. The smaller consumer grade units were the first to be phased out of the market as consumers began to want larger and larger viewing screens. Comparable LCD screens were produced and consecutively replacing CRT based devices overall, starting from smaller to larger. The price drop of the LCD screens generally then fast forwarded the changeover and forced the CRT out of market as it lost its competitive edge.

The market of CRT-based displays has seen sweeping changes over the last 5 years. To our knowledge, all CRT manufacturing has ceased worldwide and most companies, which offer any, are either end-of-stock or assembled using recycled CRT tubes extracted from disassembled used consumer televisions and monitors. Remaining brand-new stocks are rarely above quantities of 10 of the same model and often companies list stocks, which actually aren't, upon further queries, available. Having a tube refurbished is not possible as all companies within the United States refurbishing CRTs have closed, the latest within the last six months (except for military applications which is not available to the public and is only for black and white units). As of yet, no refurbishing companies have been located overseas. Furthermore, there are no remaining electron gun manufacturers left to supply the electron gun (each tube requiring its own matching electron gun). Many countries have generated laws, which restrict or forbid the manufacturing and import of CRT-based devices (for ecological reasons and to keep incoming technology up to standard with the prevailing application in use at the moment, e.g., digital instead of analog, etc.). Currently the last existing stocks that are still available, in quantity, are industrial grade monitors. These are built with extensive circuit boards to accommodate their industrial applications, which in turn, requires a much more advanced knowledge in order to service them. Their external aspect ratio is typi-

cally rectangular with an easily identifiable and distinct "monitor" look. Their cost can be prohibitive but always are worth considering on a case-by-case basis.

Some consumer grade units seem to be still available from suppliers overseas, mainly in Asia. Most of these supplies, though, are actually built using recycled CRTs that have been shipped into Asia from recycling industries worldwide. These re-assembled used CRTs combined with new circuit boards are sold to South American, East Asian, Mexican, and African markets. These "new" units and stocks are not produced for export to the United States and therefore do not have the required FDA certifications for import here. There is a market, via professional networks, eBay and the odd listing online, of used units but finding more than one sample (or even one) of a desired model proves difficult to impossible.

Electronics parts recycling centers could be an alternative within the U.S. for sourcing units, but require disproportionate manpower to assess items brought in as trash to these facilities, so identifying any potential usable units can be cost prohibitive in terms of labor. In addition electronics recycling facilities do not have infrastructure for outside technicians to verify equipment properly. Also these centers either handle the units as trash with much breakage in the passage or can only offer large quantities of a certain size units, usually of complete disparate model types of unknown origins and condition.

Unreleased stocks of new or used CRT-based displays within the United States might still be available via universities, schools and hospitals as well as from disassembled industrial display walls. A constant scanning of the market via the Internet and professional networks is necessary in order to track these sources. Finally new CRTs only (without matching circuit boards or casing) are available for purchase within the United States, but then the challenge remains to find the matching circuit boards. This is a potential course when seeking back-ups, although available compatible sizes to any given original are limited.

When searching for a back-up or replacement CRT display the original model must be analyzed to identify its key elements and function within the designated artwork. All models produced to date have slight differences, so even same size models or apparent similarity are often not interchangeable. Particular functionalities can be key to the specific art work to which the original pertains. For example in the case of large multi-display walls it is critical, unless indicated otherwise, that all units turn on when the piece receives power. The use of a manual or remote control becomes prohibitive and impractical on a day-to-day basis. In order to conserve energy, laws were passed to oblige manufacturers to build consumer grade CRT devices with a remote control "power-on" only. These models are unusable within the CRT-based video wall application for example. In addition many models produced after 1990, depend on circuit board programming via a remote control. This programming can be lost or need to be reset, depending on how the daily power on-off has been performed, as well as the length of time a programmed unit has not been turned on. A unit can appear to not be working whereas the problem lies within the programming.

Depending on the importance of the outer appearance of a unit within an artwork, replacement of the original model with a non-matching model can affect the integrity of an artwork. A consensus regarding the options for the work must be established between the artist or foundation, owner of the work and the assigned conservator. This paper presents options but without assigning choices for any particular work.

When searching for non-matching model or an alternate technology for an original CRT based display some basic factors to take into consideration are: outer case shape and visibility within the art work, display screen aspect ratio of 4:3, whether original model's CRT has a curved

screen or flat screen, viewing angle expected (display seen from far or close-up), color balance and brightness of original display in optimal desired conditions, image resolution (high-definition based devices have a much sharper image than standard definition images and CRT type images), the original model's signal input type (RF, standard definition, high definition etc.), power on-off procedures of the art work during normal operations (for example display walls cannot use units that will only function with remote-control activation); refresh rate (image scan rate which is relevant to art works displaying video game type input for example).

The first choice when seeking to migrate to a new technology is the LCD screen. Some of the options available for replacement in 4:3 aspect ratio LCD screens are as follows: Available sizes are 5, 9, 10, 13, and 19 in. These are still in production for the moment but the market follows consumer demand and can change rapidly. Within the next 2 years these units, with this aspect ratio, might go out of production giving way to the predominate 16:9 aspect ratio.

The evolution of display devices continues with new products coming out every 3 to 6 months presenting new features, which can be beneficial when seeking to restore artworks. The CRT remains a unique invention with an important role within contemporary art and art history. Technicians who have the knowledge for advanced repair are increasingly scarce. The optimal long-term solution for the conservation of CRT display based art works is still being sought. Meanwhile, the authors are consolidating whatever networks are still available within the field so as to maximize resources and to provide potentially sustained service to the community.

## FURTHER READING

Stessen, J. H. 2012. CRT degradation, CRT aging - effects on electrical characteristics and performance. http://arcadecontrols.com/files/Miscellaneous/crtfaq.htm#crteec

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