Lancaster, the "World Capital" of Television Camera Tubes

An eyewitness account by Robert G. Neuhauser

For a period of 45 years, from 1945 to 1990, the RCA facility in Lancaster was capital of the television camera tube industry. Television camera tubes are the electronic equivalent of photographic film in a television camera. These electronic devices generate the television picture from the optical image that is focused on their photosensitive surface. For many years Rochester, New York boasted that it was the capital of the photographic film industry by virtue of their hosting the Eastman Kodak company facilities. Lancaster never capitalized on its similar role in the field of television camera tubes. Not only was Lan-

Above (figure 1): These were the early laboratory or experimental camera tubes developed for broadcast TV service. On the left is the orthicon, used in experimental broadcasts by NBC/RCA. Second from left is a more advanced model of the orthicon, using a return beam system and an internal multiplier type amplifier. Next in line is one of the earliest experimental models of an image orthicon. The next large tube was a 4.5-inch diameter image orthicon. It was used for experimental purposes and TV system testing purposes. The production design of the image orthicon was chosen to be three inches in diameter to allow the production of smaller cameras using smaller lenses.

caster's RCA facility the capital and the innovative center of this industry, but the technology embodied in these products was on the highest and most sophisticated level of any field of technology in the entire electronic industry of its day. This is an eyewitness account of this specialized industry from a vantage point inside the company.

World War II and a future technology moves to Lancaster

The early 1940s, shortly after the United States entered the second World War, saw a large factory arise on the former farm of "Squire" McGrann along New Holland Avenue in the Grandview Heights section of Lancaster. The primary purpose of the plant was to make radar display tubes and transmitter tubes for radio transmission. The U.S. Navy built the plant which was operated by RCA as part of its larger electron tube operations that was headquartered in Harrison, New Jersey.

RCA had started to develop and produce radar picture tubes in the Harrison, New Jersey labs and soon moved its cathode ray and power transmission tube laboratories to Lancaster. (Cathode ray tubes are electron tubes that use a focused beam of electrons to perform their function). Included in the cathode ray lab were the engineers who were working on the development of light sensitive devices called photo-tubes and television camera tubes.

Originally the camera tube operation in Harrison was devoted to making operational samples of camera tubes. These devices were conceived in the RCA Laboratories that were originally located in Camden, New Jersey and later relocated in the new RCA Laboratories that were created in Princeton, New Jersey in the 1940s. These operational samples of camera tubes were used to make experimental television broadcasts from RCA's NBC studios in New York and were also utilized in RCA's demonstration TV studio at the New York World's Fair in 1939. (See Figure 1.)

When the development engineers

ROBERT NEUHAUSER, a native of Lancaster County, and a son of Homer and Miriam Groff Neuhauser, and grandson of Amish Mennonites,, early in life demonstrated a serious interest in things mechanical. After graduating from East Lampeter High School, he attended and was graduated from Drexel University (Drexel Institute of Technology) and went to work at Radio Corporation of America at Lancaster. Most of his life Mr. Neuhauser lived in the vicinity of Fertility which is a hamlet along the Strasburg Pike where his grandfather, Isaac Groff, owned and operated the Fertility Roller Mills.

After the death of his wife, Virginia Steward, Robert married Dorothy Killebrew, a retired Methodist minister. Active in peace and social justice movements, Mr. Neuhauser is a member of the Religious Society of Friends (Quakers) and Torch International. He also was chairperson of LINCARA, an "Overground Railroad Station" that facilitated the rescue and transportation of Central American refugees to safety in Canada. Mr. Neuhauser was a member of the delegation that attended the Paris Peace Talks during the Vietnamese War.

Figure 2:
These were the developmental models of camera tubes made during WWII for glide bomb use. Apparently they were never used in combat, being developed too late in the War. The large Iconoscope tube on the left was an experimental broadcast tube. It was reduced in size, (second from left) for the glide bomb system. The middle tube was an early model image orthicon used for further system development. The next tube on the right was a small Iconoscope tube that proved inadequate for the job and was then promoted as an amateur TV camera system tube. The small tube on the right was the MIMO (miniature image orthicon) chosen to be the production model of the tube for the Block and Ring TV bomb guidance system.

were moved to Lancaster they began to make a practical design of a camera tube conceived by Dr. Albert Rose in the Princeton laboratory. This was the image orthicon camera tube. The impetus to manufacture this tube in wartime was to make the eyes of television cameras that were to be mounted on the nose of glide bombs to guide them to their target from a remote airplane. Glide bombs were originally intended to be guided through the doors of hardened submarine pens by a bombardier flying in the plane from which the glide bomb was dropped, as he watched the view from the front of the glide bomb on a television screen. These gliders were probably also intended to be used to carry atomic bombs that could be flown to their targets by remote control to keep the guiding aircraft sufficiently far away from the target and the explosion. This use was not discussed in the course of the program at RCA since the atomic bomb program was super secret. Three different camera tubes were developed for these systems which were code named Block and Ring. These were a small version of the Iconoscope, the first practical camera tube, the full size image orthicon and the MIMO tube, a miniature image orthicon. (See Figure 2.)

Postwar research

I started working at RCA as an electrical engineering student working at RCA on a cooperative industrial assignment just after the war ended in 1946. My initial assignment was to work as an electrician in the section of the factory that produced the camera tubes, the radar viewing tubes and TV picture tubes. This section of the factory was rapidly being converted to make the picture tubes for the television receivers that RCA and others were making. The most popular tube was the 10-inch diameter tube used in the famous RCA

10-32 receiver. This nomenclature indicated that it was a 10-inch diameter picture tube in a receiver that used 32 vacuum tubes to receive the TV signal, produce the picture, and operate the picture tube.

In the camera tube manufacturing section, department 30, two types of camera tubes were being put into production. On one of my first days there I saw barrels full of the small MIMO tubes and MIMO tube parts being scrapped as the equipment to make the newly developed image orthicon tube was being put into production. They had already started to manufacture the Iconoscope tube, the first practical camera tube, that was relegated to producing TV pictures from photographic movie films. The department was managed by Clifford Lane, who eventually became vice president of the industrial tube division. The original production design of this image orthicon was made by Dr. Robert B. Janes and built by Richard Handel and Ralph Johnson in the development shop. The camera tube factory engineers were led by Danforth Cope and the test department was run by Robert Mowrer. The director of the Cathode ray lab was Dr. Lewis Headrick; the plant manager was Earl Wood; and the head of all development work was Dr. Ulrey. (See Figure 3.)

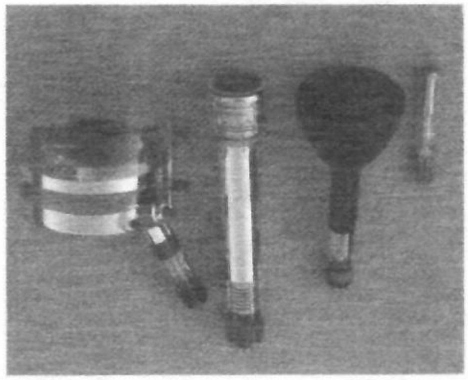

Figure 3:
A typical family of camera tubes used by the early TV stations. The large irregular looking tube on the left was the Iconoscope, used to put motion pictures on TV. The middle tube is the image orthicon, universally used in live cameras in TV studios as well as for outdoor TV programs. The small tube is the vidicon tube that soon replaced the Iconoscope for film-TV, reproduction. The cone shaped tube is the Monoscope, It produced a picture from a fixed pattern inside of the tube. This tube produced the familiar "Indian Head" test pattern picture that most TV stations put on the air when they signed off regular programming at night.

RCA had contracted to supply technical support to the USSR to build the Iconoscope tube. In between repairing factory equipment I was assigned to duplicate a test set for the Iconoscope tube for the Russian project. This unit, along with some production equipment and know-how, was destined for Russia. The equipment was never finished because the cold war heated up and RCA cancelled that contract.

I had two other co-op sessions during which I was employed by RCA.

During these assignments I observed but did not participate in the build up of production of the camera tubes. RCA began a major build- up of its capacity to make all of the equipment and devices needed to supply the growing television industry. (The name of the company was actually The Radio Corporation of America, and shortened to the acronym, RCA.) Some of us thought that the company's name should be changed to TCA to reflect the total devotion of RCA to developing the television industry.

When I graduated from engineering school in 1949, I was employed in the cathode ray lab partly on the strength of my last co-op assignment at RCA. On that co-op assignment I worked in the cathode ray laboratory and was asked to design and construct a demonstration TV "set" to operate the new large screen television picture tubes that were about to be put into production. I was asked to design and build this unit so that its circuitry would in no way limit the performance of the tube, a rather formidable objective. After it was completed I arranged to attach it by cable to a camera in the camera tube development lab so we could demonstrate the tube with live pictures. This was before WGAL began to broadcast television pictures locally, so this camera was the only source of live TV pictures. Here I was still an observer, but I associated with the fellows who were improving the design of the image orthicon tube and helping users to put this new device into operation in TV cameras that were beginning to be installed in local TV stations.

Preparing the way for color

In 1949 RCA decided that they must develop a color television system. My part of this effort was to find out what the different approaches to making a color picture tube might be, how the tubes might be shaped and what electronic circuitry it would take to operate the experimental tubes. Then I was to design and build a test set that would handle any of the tubes that would be developed following the schemes being hatched up in the RCA Princeton laboratories and the cathode ray laboratory. Picture tube design took priority since there was no need to develop a color TV system if you could not reproduce a color TV picture. In a collaborative program with the RCA laboratories, the cathode ray lab eventually developed a practical color TV picture tube. This tube evolved into the most sophisticated device that was ever produced to be used in the home. That saga is someone else's story.

I completed the test using a lot of the knowledge and circuitry that I had used to produce the picture tube demonstration set, and in the process got a good education from the RCA Princeton laboratory engineers on the technology that was being developed for the entire color TV systems. After I completed designing and building the color picture tube test set, I was asked to build a test set to operate a new small industrial TV camera tube that was conceived in the RCA laboratories. This was the first of a family of similar tubes that were to be called vidicon tubes. I hadn't the faintest idea how a TV camera tube operated, but under the tutelage of Dr. Bob Janes and Dr. Ben Vine, I rapidly began to understand the technology involved and the requirements for designing and building an instrumented TV camera that would become the test set. It was quite a thrill to eventually put a prototype vidicon tube into the test set I had designed and built and then, adjust the controls, focus an image of a test pattern on to the tube and begin to see an image appearing on the picture monitor tube. After several months of refinement and the development of special circuits and devices to perform tests on the tube, the test unit produced superb pictures and allowed the tube development engineers to evaluate and improve the tube designs. Again I borrowed heavily from my past experience and utilized much of the circuitry that I developed while building the high performance demonstration unit for the picture tubes and for the test set for prototype color television picture tubes.

The image orthicon

When I completed the test set Dr. Janes asked if I could be assigned to his camera tube group as application and test equipment design engineer. Now I could see the entire scope of the camera tube operation. The queen of the line was the image orthicon, a rare combination of sophisticated design and elegant craftsmanship on the part of the people who fabricated it in the factory. The Encyclopedia Britannica described the image orthicon as follows:

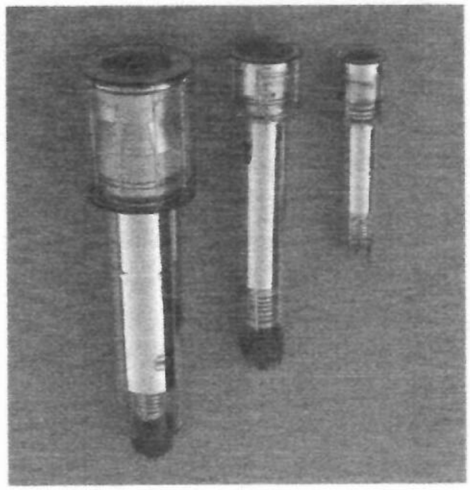

Figure 4:
These three image orthicons represent the entire family of tubes that were eventually developed for television broadcasting service.

> *The image orthicon is the most highly developed of the Television Camera tube and perhaps the most remarkable electron device in existence.* (See Figure 4.)

I will try to give an understandable account of the technology, skill and techniques needed for the manufacture and the design of this remarkable device. The purpose of the tube is to intercept an optical image of a scene that is focused by a lens onto a light sensitive surface within the tube. The tube then converts this image into a television signal. This tube has four major sections: the image section, the target, the scanning section, and the amplifier section.

Let's look at the image section first. (See Figure 5.) On the inside of the faceplate is a light sensitive surface. This is made by evaporating a very thin nearly transparent alloy of two metals such as silver and bismuth onto the inside of the faceplate after the air has been evacuated from the tube. Only one ten billionth of normal atmospheric air remains in the tube under vacuum. Cesium, another quasi-metal, is then evaporated onto this surface until the desired sensitivity of the surface has been achieved. This is done by continually measuring the sensitivity during the processing. The sensitivity over the entire useful area must be uniform to within a few percentage points. When light from the image is focused on this semi-transparent layer, the individual photons in that optical image, those little packets of vibrating energy, each transfer all their energy to an electron in the light sensitive material. The trick is to make the light sensitive film thick enough to capture the photons of light, and thin enough so that the freed electrons can escape from the back surface of the material.

High electric fields generated by voltages applied to metal parts in the image section pull these electrons away from the surface. A properly designed magnetic focusing field focuses these streams of electrons onto the target section. Each stream of electrons emerging from a spot on the original optical image lands on a corresponding spot on the target This image section had to be designed to prevent any geometric distortion of the image as the optical image is in effect transferred to the target structure where it will be temporarily stored as an electric image. This stored electric image will then be converted into a television

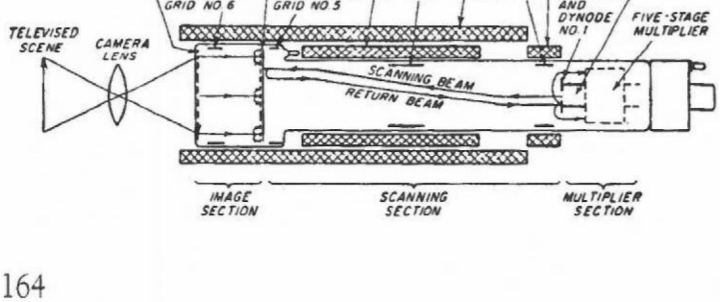

Figure 5:
A cross sectional schematic of the image orthicon tube, used to illustrate the principles on which it operates.

picture signal. (See Figure 5.)

We'll now look at how these streams of electrons coming to the target are converted to an array of electric charges that represent the brightness of the optical image at each point on the original image. Then we will see how the target is constructed. We'll first look at its construction; then we'll explain the way that the target operates and finally examine the unique technology involved in making the target structure.

The target consists of a fine mesh screen stretched in front of a thin wafer of glass. Here is how it operates to capture and store little islands of electrical charges that will eventually be transformed into a television signal. When the parallel streams of electrons approach the target, most of them go through holes in the screen and strike the glass surface. These electrons are moving fast; they possess a lot of energy. When they strike the glass surface they transfer most of their energy to a number of electrons in the glass. These electrons are "cast off from their moorings" and some of them become free to leave the front surface of the glass. We call these secondary electrons. These secondary electrons which of course have a negative charge are attracted to the nearby screen wires and land on these wires because a positive voltage is applied to the wire screen. The areas on the glass target from which the electrons left now have positive charges since they lost a number of electrons. This is also an amplification process since a single electron produced by a single photon of light in the optical image is now represented by as many as three or four positive charges on the corresponding point on the target. The target glass is a fairly good insulator so this array of electrical charges is stored on the target to await its transformation into a television signal.

The target is a marvel of technology and skill. The fine mesh screen has between 500,000 to one million holes per square inch. It is made by an electroplating process rather than by a woven wire method. To make this screen one of the most precise ruling engines ever made was constructed and installed in the plant on a ten ton concrete slab grounded in bed rock and ensconced in a climate controlled and air filtered room. A ruling engine is a machine designed to make very precisely spaced parallel lines scribing them one by one on a polished surface. A specialist by the name of Al Rene designed and presided over this facility.

The mesh would eventually be made by electroplating either copper or nickel into grooves that had been etched into a highly polished flat glass plate which would become the mesh master These grooves were made by having the ruling engine cut parallel grooves through a thin wax layer on the polished surface of a glass plate. The process was duplicated to make a mesh structure by rotating the

Loss of water in a boiler produced a catastrophic explosion; therefore someone had to be delegated to sit watch alongside the boiler day and night to watch the water level in a sight-glass tube. Remote instruments could not be trusted but a TV picture could!

The vidicon tube was a much simpler tube than the image orthicon. It operated on the principle of photo-conduction. This means that instead of freeing an electron from a surface of the light sensitive material, it freed up electrons within the light sensitive and allowed them to move through that material. Camera tubes using these photo-conductive light sensitive materials were less sensitive than the image orthicon and moving objects tended to smear out. Because of the lower manufacturing cost and the simplicity of the vidicon family of tubes and their associated camera, vidicon tubes eventually became the major type of camera tube in the industry.

The old Iconoscope tube did a lousy job of putting movie films on TV. I recognized the potential of this new vidicon tube and guided the development of a new version of the vidicon tube for cameras designed to put motion pictures on TV. I developed the unique methods of operating the tube for this service and demonstrated the performance of the tubes in motion picture service by projecting a motion picture onto a vidicon tube in the vidicon test set. Shortly after demonstrating this system to representatives of the television equipment industry, it rapidly became the standard camera tube for the cameras designed to transfer motion picture films to television.

Medical uses for the image orthicon

The image orthicon soon came into another pioneering role. I had just completed an analysis of the comparative sensitivities of the different camera tubes when we got a call from Johns Hopkins Hospital scientists working on X-ray problems. X-Ray fluoroscopic studies are examinations where X-rays going through a patient light up a fluorescent screen that the doctor observes to make a diagnosis. This subjects the patients to huge doses of X-rays and the doctors had to put on dark glasses for a period of time to dark-adapt their eyes before they were able to properly view the faint image on the fluoroscopic screen. Taking motion pictures or photographs of the screen introduced a delay in the process. They asked if we had a TV camera tube that was more sensitive than photographic film and would allow a doctor to examine the X-ray picture from a more remote and safer location. I told them that the ASA equivalent of our image orthicon was between 10,000 and 20,000 compared to film that rarely had an ASA rating over 1000. They didn't quite believe that and asked for a demonstration. As we cut down the light level in the test that we performed for them and they saw the quality of the picture the camera produced, they practically danced for joy. Johns Hopkins immediately bought TV cameras for more experimentation, and the entire industry of X-ray image intensification and remote viewing of such things as heart artery catheterization was born. Unfortunately because of some adverse patent claims, RCA opted to stay out of this business itself other than to sell the camera tubes that were used in the equipment. Medical X-ray image intensification, as it was called, developed rapidly and soon became a major industry.

Making color television a reality

By now RCA was determined to make color television a reality. The picture tube group was put into a crash program to develop and put a color picture tube into production. The rest of the company's technical resources from the TV receiver group back to NBC, RCA's broadcast network and the broadcast equipment group that produced the cameras, studio equipment and TV transmission equipment went into high gear.

The first color cameras used three of our image orthicons, one for each of the red, blue and green channels. As the application engineer, I consulted with the RCA Broadcast equipment group as they built the first TV cameras to be used in experimental color broadcasts. I could never get enough time in the cameras that were under development and experimental use to properly evaluate the performance of tubes in this service so that I could intelligently recommend modifications that should be made to make the tubes suitable for color camera use. Soon I was given one of the first three complete experimental color camera systems ever made to use in Lancaster. I installed it in a small studio I had built in the "penthouse" on the factory roof. When necessary we set up a stage production and piped the color pictures from this camera to the group that was developing the color picture tube so that they could more realistically demonstrate the performance of the developmental color picture tubes.

About this time, the powers that be decided that a person of the caliber of Dr. Robert (Bob) Janes should be working on the development of a practical color TV picture tube and he was transferred from directing the development of light sensitive tubes (including camera tubes) to the picture tube development group. To my surprise Franz Veith took his place and I was made head of the group of engineers developing camera tubes. This was a small group consisting of David Marschka and Ben Vine working on the design of vidicon tubes and Alex Rotow working on the new image orthicon designs and modifications. I continued doing the field application work and test set design since we now had a good group of technicians who could fabricate any of the test equipment that the application engineering and tube development engineers required.

Licensing the technology

Up until about 1956 RCA had no effective competition in the camera tube field. If you wanted a camera tube you came to RCA. If you wanted to broadcast television you had to have camera tubes. On the other side of the coin, if anything ever happened to that corner of the RCA factory housing department 30, the entire TV industry would be held hostage to its being rebuilt. David Sarnoff, the founding father of RCA, decided that if TV, and particularly color TV, was to take off and become a worldwide enterprise there should be some common standards and equipment. He decided to license any and all comers to RCA's patents and to supply for a fee, the technical know-how to build any of the TV products that RCA produced. RCA even contracted to build for these licensees any and all of the production equipment to make any of our TV products. Many of us were appalled to see teams of engineers from around the world setting up temporary residence in the plant and copying all of our hard earned techniques. In retrospect I believe it was a good decision. The patent and licensing group became a major profit center for the company. The competition from other new manufacturers striving to make improvements or innovations in order to get their foot in the door of television broadcast stations where the station engineers were firmly committed to RCA's products, gave us an incentive to stay ahead of them and introduce needed innovations.

This decision to license all comers to RCA's television patents and technology produced the desired results. A nearly universal standard of technology was adapted throughout the world which made worldwide television communication practical. Some countries adopted different transmission standards, possibly with the intent of preventing programs from other countries from contaminating their culture by making it difficult to receive transmissions from another country, but the hardware and the design of most television equipment followed the basic design of RCA's patents and technology, allowing others to rapidly get into television broadcasting. They didn't have to reinvent the TV system and technology.

Developments during 1950s and 60s concentrated on developing the special types of camera tubes to produce color studio and color television-film cameras so that when color television took off, the necessary studio equipment could be provided. I spent a lot of time traveling to NBC New York where experimental color TV studios were set up to help develop system standards for color TV broadcasting. These standards were being developed by the National Television Systems Committee, (NTSC). This industry wide organization was entrusted with the task of developing a color television broadcast system that could transmit either color or black and white pictures that could be received on existing television receivers. These standards eventually became the US color TV broadcast standard. We introduced new and improved versions of our camera tubes into these experimental cameras and conducted field tests to establish performance standards for the tubes to be used in these cameras. New photo-sensitive materials were incorporated in the tubes to get the required sensitivity and color response and precision structures were devised to better assure that the three color images would precisely line up with one another when the signals from the three camera tubes were combined to produce the final color picture.

RCA was determined that the complete color system from the cameras through the studio equipment, the transmitters, the telephone company's microwave transmitter and coaxial cables through which the signals would be carried across the continent, as well as the design of the color TV receivers for the home would be capable of handling the color TV signal with the required precision. To review this entire system they created the RCA Color TV committee which met periodically to review the bottlenecks in the system and make recommendations for areas where improvements should be made. I was made the representative of the camera tube operation on this board. This provided me with an unequaled perspective on the amount of effort the company was pouring into color TV work and helped me guide the development of the devices that we made which actually created the color television images.

Redesigning the Vidicon

During this time it became obvious that the design of the vidicon tubes would have to be drastically revised if they were to be made in large scale production and made with the precision required for color television. We eventually designed and put into production a whole new line of vidicon tubes for the cameras used to broadcast color movies. First I'll illustrate the basic design of the vidicon tube and then illustrate the new technology we devised to make it more manufacturable and thereby enable this family of tubes to eventually take over the television camera tube market. It is a much simpler tube than the image orthicon. (See Figure 8)

The vidicon tube utilizes as its light sensitive element, a photo conductor that is deposited on a transparent electrode that has first been deposited on the inside of the glass faceplate. A photo conductor is a material that has the property of changing its electrical resistance when light falls on it because the

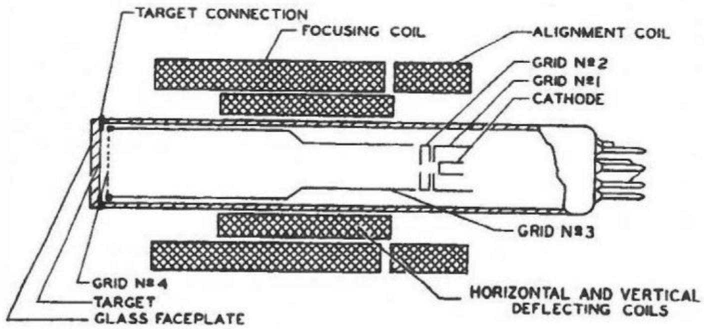

Figure. 8:
This illustration illustrates the relative simplicity of the vidicon line of camera tubes that operated on the principle of photoconductivity. A photoconductive material is a material that changes its ability to conduct electric current when it absorbs light.

light frees up electrical carriers that can move through the material. Behind the photoconductive layer is a mesh screen that shapes the electrical field between the photo conductor surface and the electron gun structure. The electron gun produces a fine scanning beam that is focused to a fine spot by an external magnetic focusing field, and the beam is deflected in the scanning process by a pair of magnetic deflecting coils surrounding the tube.

The first vidicon tube design required that the photo conductor be deposited on the faceplate by pushing a small boat of the photo conductor material into the center of the tube through a thin glass tube attached to the side of the glass bulb. The boat was then heated in order to evaporate the material onto the faceplate (and unfortunately on to the mesh) in the vacuum inside the tube, and then heating the mesh to remove any photoconductive material on it. Then the boat was pulled out of the bulb and the glass appendage was sealed off. All this was done in a vacuum environment inside the tube. This was a messy and imprecise process and did not lend itself to production of high quality tubes or to mass production. We did find that the photoconductive layer of antimony trisulfide could be exposed to atmospherically controlled air after it was formed, so that allowed us a great deal of flexibility in the design and manufacture of the tube.

I instituted a program to see if we could make the photoconductive layer on the faceplates in a mass-produced manner and then seal the faceplates to the tube before we did the final processing and exhausted the air from the tube. A lot of schemes were tried including gluing it on with the newly developed epoxy plastics, but none of them were compatible with vacuum technology. Dr. Ben Vine began to look at other materials. One day he rubbed a piece of the soft metal indium across glass and found that it left a streak of metal that was tightly bonded to the glass. Apparently indium always develops a thin layer of indium oxide on its exposed surface. When this thin layer of oxide is rubbed off the indium grabs oxygen in the glass and forms a tight bond. He and Timothy Benner rapidly developed a system to deposit the photoconductive material on a faceplate, inspect it for mechanical defects, and then seal the faceplate to the end of the bulb with an ingenious method. They squeezed a ring if indium between the faceplate and polished end of the bulb in such a way that fresh unoxidized indium was pushed across both glass surfaces and made a good mechanical as well as a vacuum tight bond between the end of the cylindrical bulb and the flat faceplate. At the same time, the indium metal made electrical contact to the transparent signal plate on the inside of the faceplate.

This revolutionized the technology and most camera tubes designed from that time on use this technique of manufacture. Now we could make tubes with precise geometry, batches of photo conductors could be made and a sample of each lot of photo conductor coated faceplates could be tested for performance before the entire batch of coated faceplates were assembled into tubes. Certain spots and defects could be detected and those units could be discarded before being built into a tube. All this cut the manufacturing costs and allowed the widespread use of low cost closed circuit television. David Marschka and Ben Vine began to rapidly develop new vidicon tube types using this technology for both the industrial and the TV-film cameras for the broadcast industry.

Dr. Vladimir. K. Zworykin, vice president of the RCA Labs and inventor of the first practical television camera tube thought that low cost TV cameras should eventually be used in most retail establishments, as backup viewers for trucks and as babysitting monitors in every home. He got the money for us to develop a miniature low cost vidicon tube that could be sold for $10.00. We developed the tube but the marketing department could not find a customer willing to go into large scale low cost camera production so the design was shelved. We also found that just making the tube smaller did not reduce the cost of manufacture!

Working with the British

While color technology was gestating and before the TV networks began to convert to color we got into a new design of an image orthicon. In the early days of the development, a large diameter, 4-inch tube was made on an experimental basis to see if it would produce a sharper picture. The 3-inch diameter tube was decided upon as having adequate resolution for the TV system but several examples of the 4-inch image orthicon graced our "trophy" shelves.

Our United Kingdom licensee, English Electric Valve (EEV) was being pressured by the BBC (British Broadcasting Company) to produce tubes with a higher resolution. They saw our samples and asked for the drawings so that they could experiment. BBC was a very demanding customer and EEV's biggest customer. The EEV's chief engineer told us that we should get down on our knees every night and give thanks that we didn't have the BBC for a customer. Having BBC as a customer was actually a plus for EEV since they were pushed toward excellence. EEV was very innovating in producing improvements in design and performance. They became our most formidable competitor and dominated most of the international market. Fortunately our licensing agreement with them allowed us to use any of their patents and designs so we kept pace with each other in technology.

EEV produced a modified 4-inch design tube in consultation with our engineers and we jointly developed a line of these tubes. RCA designed a camera to use them. By this time Paul Kaseman had been transferred from camera tube manufacturing to our laboratory and shepherded the design of this tube. This tube did introduce a new level of picture performance in black and white cameras, and EEV and RCA camera tube operations jointly received the EMMY award given annually by the Institute of Television Arts and Science for technical achievements in the TV industry. The cameras using this much bulkier tube were rather large, and most broadcasters declined to go the route of higher resolution when color television with its obviously broader appeal was on the horizon.

One of the first programs that I initiated on image orthicon development was the search for a long life target. It became very obvious to me that if someone else solved the problem of targets becoming sticky and holding an image in a semi-permanent state after about 500 hours of use, we would be in big trouble. Besides I thought we owed it to the customers to make a longer life product, considering the price that they paid for our tubes. The problem was that electrons flowed one way through the target glass by dragging ions of oxygen along with them. These oxygen ions apparently reacted with cesium that was unavoidably deposited on the surface of the glass and made a high resistance layer on the front surface. We verified this mechanism many years later when Ben Vine, Tim Benner and I worked out a very sophisticated test and an unique piece of tube processing equipment that revealed the true nature of this problem.

Our English Electric licensees were also working on the problem. We rightly thought that we needed a glass or other target material that would conduct by electronic conduction instead of dragging oxygen ions through glass. Our consultants in the RCA Laboratories suggested an approach to a glass composition that might accomplish this, and we turned to Corning Research Labs to supply the samples of experimental glass. EEV did their own glass composition work using the same approach and developed a target glass that did not become sticky with use. We both put it into production to the everlasting gratitude of the TV station engineers.

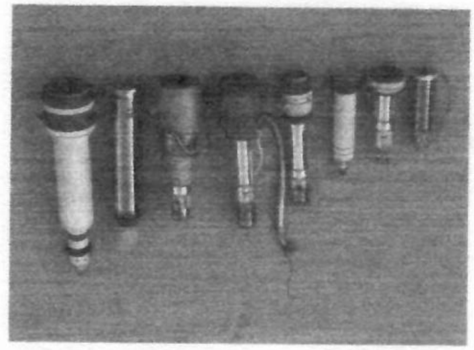

Figure 10:
A family of the miscellaneous special purpose vidicon tubes developed for Military or space applications. Many of these tubes used the more sensitive and rugged Silicon Target.

Color television at the World's Fair

To promote color TV RCA set up a complete color TV studio and color TV theater at the World's Fair in Flushing Meadows, New York. We equipped this studio with experimental and regular production tubes and used the experience to further guide our development work. Color TV broadcasts began to become rather frequent and when RCA began producing color TV receivers in large quantities, our business started to skyrocket. Now we not only were supplying tubes for the new cameras in these newly equipped TV stations, but each camera utilized three tubes instead of one.

About this time the management realized that the facility we were using to produce camera tubes was not only inadequate in size, but it did not provide a clean enough environment in which to produce tubes that were sufficiently free of blemishes. A program was undertaken to build a new factory for the production of any tubes requiring an ultra clean environment. Inside the new building, a special clean room was constructed. The air was to be fully air conditioned and the air entering the room was to be filtered as well as the state of the art would allow. All air was exhausted through grates on the floor that occupied a large part of the floor area, all pipes and wiring came up from below to avoid having overhead structures that could collect dust or shed debris. The air first traveled through conventional filter systems in the basement and then traveled to the ceiling

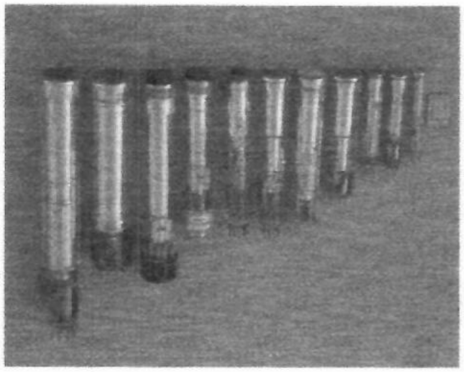

Figure 9:
This illustrates the family of various vidicon tubes that were put into production and had a very long and profitable product life. They range from the high resolution tube on the left used for the later color TV film reproduction cameras to the tube on the right that produced the first TV photos from space in the TIROS weather satellite. On the far right is one of the early silicon chip imagers that eventually replaced nearly all of the camera tubes.

chamber where ultimate filters took out any very fine particles. The entire ceiling area was essentially covered by millipore filters which are the type of filter designed by the beer brewing industry to filter yeast out of beer so that it will not continue to ferment in the can or bottle. This was probably the largest and cleanest room in the world and the camera tube operation began to move into this building.

I got involved in an interesting sidelight that led to a major medical breakthrough. People were making oriented fiber optic bundles where they could focus an optical image on to one end of a long bundle of flexible fibers and show the same image on the other end of the bundle of glass fibers. I got a request to see if we could somehow incorporate the end of a fiber optics bundle into a camera tube so that a TV camera could show a picture of an image that was being put into the other end of the fiber bundle. That looked like a wrong approach so I asked if they could fuse the one end of the glass bundle together by bringing the glass to the melting point and then slicing off a thin layer of that glass in the dimensions of the faceplate of one of our tubes. It wasn't long before several appropriate pieces of glass showed up. I had them checked for vacuum tightness and then polished to the proper degree. These fiber optic faceplates were then incorporated as the faceplate of one of our better quality vidicon tubes. The developers of the fiber optic system were ecstatic. When they butted the fiber bundle against the fiber optic faceplate of our tube in a television camera they could see the image being put into the other end of the fiber bundle. This was the start of the endoscopic medical procedures business where internal examinations and major surgery are accomplished by putting a fiber bundle equipped with a lens and light source into a body cavity. The physician then diagnoses via the exploration and/or performs an operation while viewing the inside of the patient through the fiber optic television system.

Tubes in space

NASA and the Military began to look at television technology. RCA got many requests to propose television technology for their projects. I declined to work on military programs. To me most of the NASA programs also looked like military programs so the management decided to set up a separate government oriented camera tube operation that was to be funded with government contracts. David Marschka was selected to head this operation and he took several of our other camera tube engineers with him to set up this operation. The first project they undertook was making a special camera tube for NASA's orbiting weather satellite camera. The vidicon that they developed was adapted from the small tube that we had developed and shelved. This became the eye of the TIROS weather satellite, the first TV camera to orbit the earth. It broadcast pictures of cloud cover and storms for many years. Later this group developed a number of specialized camera tubes for classified military and NASA operations, and developed an extraordinarily sensitive camera tube based on silicon technology. One of their more spectacular successes was the development of an intensified Silicon Target tube dubbed a SIT tube which accompanied the astronauts on the Apollo moon landing and relayed to the earth, pictures of their first steps on the surface of the moon.

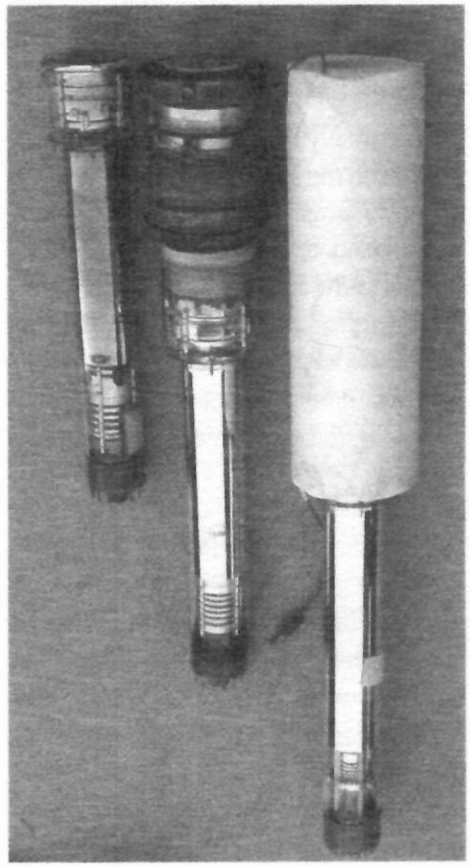

Figure 11:
These are representative of the more exotic version of the image orthicon family, developed for Military or Space uses. They were used for such things as guiding planes to a landing on Aircraft Carriers at night and searching for space debris.

By this time, the production and development of all light sensitive tubes that converted light into electrical signals was combined into the Conversion

Tube Group, under the direction of Dr David Epstein who had been a researcher at the RCA Princeton Labs. He eventually initiated a major reorganization of the Conversion Tube Operation. The engineering manager decided to consolidate all of the camera tube development in one group. Since I was unwilling to engage in making "instruments of death and destruction" I was put into an advanced development group to develop new generations of products.

Beyond the image orthicon

About this time Philips, a Holland firm that had tried to get into the image orthicon business and failed, was working on a new photoconductive tube that promised to have the necessary sensitivity and a better ability to capture motion than did our vidicon tube photo conductor. This program was based on lead oxide, a common ingredient of paint. Philips had demonstrated this over a period of thirteen years but they could not produce a tube that lasted for more than a few days in operation. Suddenly they seemed to have solved that problem and began demonstrating these cameras at the broadcaster's conventions and engineering seminars. The much smaller camera that they could produce using this tube appealed to broadcasters so suddenly no more image orthicon cameras were being bought. Our advanced development group began to work on other photo conductors proposed by the RCA laboratories, but we were unsuccessful in producing a suitable product using these materials.

Management finally decided to duplicate the Philips tube. We did have a cross license for patents with Philips but no technical know-how agreement. RCA realized that its profitable broadcast camera tube business was going to nearly disappear unless we came up with a competing product. A special task force was set up to duplicate the Philips tube using information in their several hundred page patent. This patent covered every conceivable means of making a lead oxide photo conductor and any possible combinations of processing techniques, with no clue as to which ones actually worked to produce a usable photo conductor.

I quickly built equipment to test the tubes that were to be built and helped to get the prototype production equipment built. Since the task group was created by assembling a group of engineers from several departments it soon became evident that it required its own structure and I was selected to run the operation. This was designated as a crash program and was given top priority within our operation. Our task was to get the needed production equipment designed, built, and modified on the fly based on inputs from the engineers that were developing the photo conductor and the tube making processes. The photo conductor had to be "grown" inside the bulb while under a proper oxygen-water vapor partial vacuum, since it was evident that this photo conductor could not stand exposure to air. EEV had decided that their future business required the same approach. They actually started working on the lead oxide photo conductors several months before we did. We began an extensive collaboration with EEV that extended over the life of the program.

By the time that the production equipment was designed and built we began to have some success. We could actually make a few tubes that performed quite well, and introduced some tube design improvements that we thought would appeal to the TV broadcasters. By this time, Philips had made a special tube that had extra red sensitivity for the red channel of the camera. Their normal tube was deficient in red sensitivity and did not reproduce red parts of a scene very well.

I recommended starting up our production and I got the factory operation going fairly well, while still supervising the photo conductor development. Development effort was switched to getting a red sensitive tube in our lineup since broadcasters were reluctant to mix and match different manufacturers tubes in their camera, and were unwilling to mix our standard tubes in cameras using a Philips extended red tube.

Production yields were lousy because of variable performance of the photo conductor. Some weeks we couldn't make a single good tube and had no idea why. The red sensitivity program rarely generated a useful device. We operated the factory as a joint development and production shop for about a year and got the production yields above ten per cent. Management thought that putting the operation in the hands of an experienced factory manager would cut the variables out of the program and produce a consistent product so Bill Hackman was given the entire program and ran it for several years while I handled the TV station and camera designer contacts and the introduction of our product to the broadcasters. RCA never did solve the red sensitivity problem. The image orthicon business disappeared in the late 1970s and in the early 1980s the lead oxide program was terminated because it was unprofitable. Philips was now the king of the TV broadcast camera tube business.

For a while, we toyed with a novel vidicon tube that was designed so that a single tube could produce a color TV picture. This was to be a tube that could be used in a home TV camera or an industrial color camera. The tube used our vidicon structure and photo conductor, but on the inside of the faceplate we made a sophisticated color filter structure that would generate two distinct electrical tones in the picture output signal that could be separated out and eventually translated into a color TV picture signal.

I was asked to evaluate the tube and the techniques and try to determine why the performance was so poor compared to the performance you could get from such a scheme if you projected an image through similar color filter structures on to the photo conductor. I decided that the process of making the filters for the inside of the tube was flawed and would be a failure unless a major change was made in the approach to making the fine color filter stripes on the inside of the faceplate of the tube. RCA dropped the program and two US manufacturers who were attempting to make home video color cameras with this technology also dropped their development programs. A Japanese company (Hitachi) took a brute force approach to the problem using the approach that I had recommended, and made the first generation of home video cameras and from then on Japan dominated this field.

RCA had some other interesting camera tube operations going on. Dr. Ralph Simon, previously of the RCA Princeton Laboratories, was appointed vice president of our conversion tube operations. The RCA laboratories had recently been experimenting with silicon chips as detectors of light and silicon chip structures that could detect and store an image that in turn would be read off by an electron beam in a vidicon type tube. He brought two scientists from the Princeton Laboratories with him namely Dr. Richard Savoye and Robert Rogers. They began to make tubes with these silicon targets that had very high sensitivity and fairly fast response to moving images. The silicon targets were made with the technology that is similar to the technology with which all solid state electronic devices are now made. They thought that these tubes would replace all of our products in short time. They were successful in making the design of a very sensitive photoconductive silicon chip which could be put into a rather conventional vidicon tube. Though more expensive than our vidicon tubes, they were more robust and began to have wide use in industrial TV cameras. When these tubes had some initial success funds began to be cut off for development of other types of tubes in the expectation that the silicon technology would replace the broadcast tubes as well. Talent and funds were diverted from other tube development programs and engineers were reassigned to the silicon program. In spite of a lot of good work and hard tries the silicon tubes were never successfully accepted in any broadcast TV applications.

There were some outstanding successes with the silicon technology. These were the Silicon Intensifier tubes mentioned previously. An image section was coupled to the front of a rather conventional vidicon tube with a silicon target mounted in front of the electron gun. The photo-electrons originated from the photo-cathode at the front of the image section of the tube, similar to an image orthicon image section but operated at a very high voltage. These electrons bombarded the silicon target and generated many electric charge carriers within the silicon target that could be read out as an amplified image. These tubes could literally produce a usable picture of a scene illuminated by starlight. When they attached a second image intensifier section onto the first, the tube was sensitive enough to detect and display individual photons of light coming in to form the image you saw being built up on the TV picture tube. This family of tubes saw a lot of military and special purpose use.

Mastering the silicon chip

The next generation of devices developed by the silicon group were silicon chips that could detect an image and produce a TV picture from within the chip without the need to read off the image charge with an electron beam. The successor to these silicon chips are in the digital cameras and camcorders that are now in nearly universal use. These devices eventually spelled the end of the profitable camera tube business throughout the world. Again RCA was the pioneer in this field.

When Savoye and his team started the design of these chips in Lancaster they used the clean room and ruling engine facilities to the their best advantage. They produced devices that worked and devices that were far more sensitive than similar prototype devices being developed in Japanese laboratories. The RCA Broadcast Equipment group which was being hammered by the competition in small color cameras and advanced tape systems from Japanese manufacturers decided that they had to leapfrog the industry. A company wide crash program was started to develop silicon chips suitable for a broadcast camera. This camera would be a small and rugged broadcast color TV camera with a built in video tape recorder for electronic journalism work. The camera and silicon chip development work was started simultaneously and when they solved the major problem of the silicon chip design by putting a rotating mechanical shutter in the optical path to avoid streaks in the image as the picture was read off of the chip, the camera produced superb pictures. This prototype camera and the new silicon image chip technology was the toast of the Broadcasters National Convention where it was demonstrated. The yield of good silicon imaging chips in our facility was abysmally low. It was estimated that a 300 million dollar factory of the caliber of those being built to produce computer chips was necessary to produce the quality of image chips required by the broadcast industry. When the Broadcast Division was told that they could buy the chips from our factory at the factory's production cost and that the production cost estimates exceeded the price at which they could sell the entire camera, the Broadcast Equipment group shut down their solid state camera program. Lancaster then closed its silicon chip program and within months the RCA Broadcast Equipment division closed down. An era was over.

The effort did produce one benefit. Samples of the silicon imaging chips were tried by astronomers and proved to be much more sensitive than film for recording celestial images. RCA's entire stock of usable chips were sold to the astronomy industry and now these types of sensors are nearly universally used in astronomy instead of film.

By now the broadcast camera tube business was essentially defunct except for some replacement vidicon tubes. Some specialized versions of the image orthicon were still being used for NASA and military programs, but by the late 1990s the camera tube business was only a shadow of its former self.

In 1986 when GE offered to buy RCA it became obvious that they would have five too many color picture tube factories, two too many color picture tube development groups, one too many research labs, one too many solid state divisions, one too many service corporations, one too many TV set manufacturing operations, one too many camera tube operations, one or two too many space hardware centers, one too many military electronics contractors and about 150 too many vice presidents. When an offer for early retirement was made in October 1986 I said *sayonara* and retired from camera tube work. My career spanned both the rise and the ebb of RCA's reign as the world capital of television camera tubes.

Many fine engineers and technicians occupied the buildings on the site of Squire McGrann's old farm and contributed a lot of ingenious solutions to the myriad problems of designing and making television camera tubes. I cannot recall the names of all of them or give them their proper due in this story; it is, after all, an eyewitness report and eyewitnesses are not known for their complete veracity and accuracy nor for total recall. I've done my best.

Appendix

Personnel involved directly with camera tubes at RCA Lancaster, PA, in a management or professional technical role, 1946–1986. We apologize to anyone we may have missed. Please let us know so we can correct any errors.

Scott I. Alexander
Harry Aulthouse
Donald Battson

T. Benner
Charles W. Bizal
David L. Brubaker
J. Donald Cammerata
J. J. Carroll
G. Dale Cartwright
Tien Chin
David H. Cooper
Danforth Cope
W. T. Dyall
Eugene Dymacek
Thomas W. Edwards
Daniel Eister
Fred Engstrom
Ralph Engstrom
Dan Eyster
Elmer Faller
Robert Frutiger
Alvin Gantz
Theodore J. Grabowski
Leonard Grove
Leonard W. Grove
Willard H. Hackman
Henry Hambleton
John Heagy
Fred Helvy
Fredrick A. Helvy
John Herrington
Richard Hoffman
Robert Holton
John Holtzapple
Victor Houck
Paul Huston
John Inslee
Robert Janes
George Jannery
Ralph Johnson
Kenneth Johnson
Paul Kaseman
William M. Kramer
John Kuehne
Clifford Lane
Solomon Lasof
Joel Leaman
Robert Lee
Thomas Lewis
Charles Lilley
William Little
William Lynch
Albert Mannon
David Marschka
Robert Mazeski
Lewis Miller
Richard Miller
Roy Minet
Clyde Mock
Albert Month
Robert Mowrer
Elvin Mussleman
Robert Neuhauser
Charles Newcomer
Steven Ochs
Fred Peterson
Maxmillian Petrisek
Richard Phillips
Hans Popp
Charles Rector
Donald C. Reed
Philip Richards
Carl Rintz
George A. Robinson
Robert Rogers
Wayne Rohland
Alexander Rotow
Philip Rule
Richard Savoye
Harry Seelen
Ralph Simon
Morris N. Slater
Edward Smith
Richard Spaulding
Jay Stouch
Jackson Straub
Joseph Supulski
Daniel Thoman
Robert Toppmeyer
Robert VanAsselt
Franz Vieth
Benjamin Vine
Frank Wallace
Herbert Werner
Charles Widderr
Wayne Winters
James Zollman