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CCTV IN THE UNITED STATES

The first US manufacture of CCTV equipment was established in 1946 by a major manufacture of large power plant boiler systems to fill a need that was not available on the commercial market. The company had just finished commissioning a large 1 mega-watt power generation system for a Virginia Utility. Several days after startup the boiler lost water and exploded, placing the boiler out of service for over a year. Water level gauges are located approximately 3 stories above the control room. Prior to the development of CCTV gauge viewing, a system of mirrors was used to reflect the gauge image to the control room. One of the mirrors at Virginia Electric Power had been damaged and the control room was not able to monitor the. When the water level dropped below the minimum the boiler exploded and was heavily damaged.

The boiler manufacture searched the available technologies and found that towards the end of the Second World War, CCTV had been used aboard naval ships for remote viewing. A search of patents reveled that Philo T. Fransworth had been issued a patent on an Image Dissector Television Pickup tube. The boiler manufacture purchased the rights and began manufacturing remote CCTV gauge viewing systems using the Farnsworth design. These cameras were very large, heavy, had 200-line resolution, bad “S” distortion and required a lot of light and power.

In the early 1950’s the RCA Corporation commercially introduce the Vidicon imaging tube. This now allowed the development of smaller cameras (5” diameter) that could fit in 8” and larger pipelines. Again the power generation industry began purchasing these cameras, built into a waterproof housing, to inspect water intake and discharge lines. As municipal governments owned many of the power utilities, their wastewater departments would see the power plant inspections and then began to “borrow” the cameras to check their sewer problems. These cameras were smaller, had better resolution, were more fragile and very noisy (electronic) when moved over debris and joints.

In 1963, a contractor and a major chemical manufacturer were asked by the Federal Government to develop a method to quickly and economically seal ground water infiltration into sewers. From this research, two-part pipeline chemical grouting was developed. However to test and seal a joint required a modified pipe plug called a chemical sealing packer. A chemical sealing packer looked like a pneumatic pipe plug accept it had sealing chambers at each end and a void area in the center where the two chemicals were injected under pressure. However to place the packer on the joint the operator had to see the location of the joint from inside the pipe. The contractor began purchased cameras from the boilermaker and started using them in the sealing of wastewater lines. City crews again seeing the pipeline CCTV became interested in obtaining their own systems. As the boiler manufactured was not interested in this market the contractor began marketing CCTV wastewater inspection system to wastewater utilities. In 1964 the CCTV equipment business was spun off as a separate company, which continues to serve the wastewater, and other markets to this day.

Today CCTV cameras use solid state imaging arrays that are very rugged, require less light and are highly reliable. This has resulted in the universal acceptance of pipeline CCTV inspection as a necessary tool in managing underground utilities.

HISTORY OF CCTV IN THE UNITED STATES

Welcome to our discussion of Closed Circuit Television (CCTV) in the United States. First we should start with the definition of the word sewer, which many believe has its' roots in the Old English word seaward. The old sewers in England were open ditch style and led towards the Thames River which then flowed towards the sea. Therefore the liquid in the ditch was referred to as seaward.

The earliest pipe recorded in use in the United States was simply hollowed out logs which carried sewage from a single dwelling the nearest stream. This of course polluted the waterways and was not in use for long before sewage system in more urban towns became commonplace.

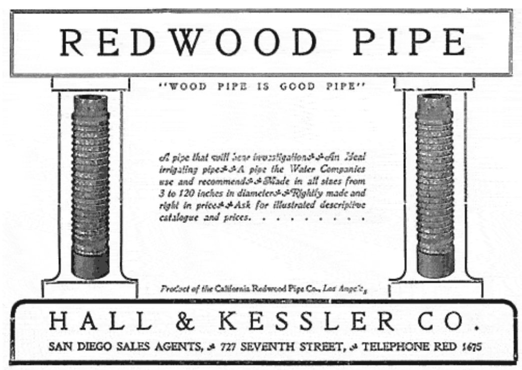

Figure 1. Advertisement for Redwood (Stave) Pipe
Manufacturer: *California Redwood Pipe Company* (Los Angeles, CA).
Source: *1924 Classified Buyer's Guide of the City of Monrovia, CA*.

After we started with sewer systems, the need for inspection and cleaning quickly arose. The beginning of sewer line inspection was not with CCTV, but rather a primitive test which was only really capable of finding infiltration or a failure of the so called inspection method.

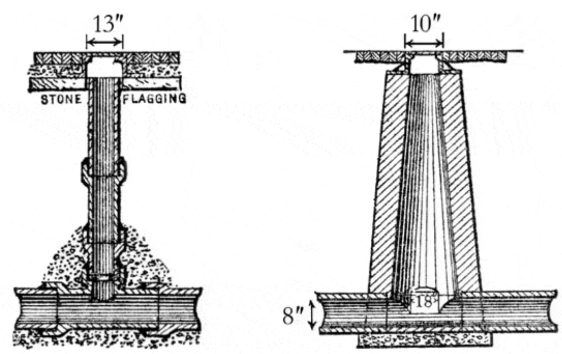

Figure 2. Lamp-hole Designs
Source: *The Designing, Construction, and Maintenance of Sewerage Systems,*
by H. Prescott Folwell, 1901

The first holes which were used to access the collection systems were referred to as lamp holes. They were only large enough to lower a lamp which was used to see if light would appear at the other end. The interesting part of these early inspections is that no camera was used, these lamp holes were used to lower a candle and in later years the candle was dragged from one manhole to another by floating a thin line, such as a fishing line downstream with the flow and then retrieving it at the downstream manhole. This thread was then used to allow the operator to later pull a sled or a wagon through the line. On the sled or the wagon a candle would be placed. It was felt that, if the candle would still be lit at the far end if there was not a problem with the line. If infiltration occurred, then it was thought that the candle would be extinguished. This of course also remained true if the candle went past a lateral with flow, or rolled over during the inspection also. Not much useful information was gathered. At the end of the day, the operator would have a simple set of data which showed if a line passed or failed. A failure usually meant a re-inspection. If an actual failure did indeed occur, then operator still had no idea where in the line the infiltration occurred.

Early pipe was built in 2’ sections and was not sealed at the joints as it was felt that a little ground water infiltration would increase the velocity of the pipe and thereby increase its’ self cleaning ability. Later proper construction analysis disproved this and 3’ pipe lengths were introduced as the dirt and debris was entering the line causing blockages. The use of sealant became proper construction method. The early lamp holes were slowly replaced with manholes. The manholes provided two purposes. Firstly, they allowed access to the collection system for maintenance purposes. Secondly, they provided much needed ventilation. Earliest plumbing didn’t have water filled traps and the larger manholes with ventilation lids allowed the ventilation required to remove the odour which had become synonymous with indoor plumbing. Now with larger manholes for the purposes of maintenance, a true value could be attributed to the inspection. After all, what was the purpose of inspecting a collection system if there was no way to maintain it? At this point we now needed a way to see what was underground, and where underground the failure had occurred.

Enter, George Eastman and the Kodak Company. In 1880 Kodak started manufacturing cameras, the candle was replaced with battery powered lamp, and the system was updated to include a photographic camera. Now the inspector could have a collection of still shots showing the condition of the system. The still shots if timed correctly could also correlate to a distance from the starting manhole.

Figure 3. 1900 Magazine advertisement for the popular BROWNIE camera
Source: *http://www.kodak.com/US/en/corp/kodakHistory/buildingTheFoundation.shtml*

By 1890, the city of Newton, MA. began to ventilate in its street sewers with very beneficial results. Now the odour associated from the sewer line was not prevalent at the kitchen drain nor at the manhole in the street and more attention was being given to sewer line construction. In particular to the proper forming of sewer junctions to prevent deposits; smoothness of perimeter to prevent retention of solids; the grade when proportioning rainwater capacity and most importantly for our purposes straight mainline alignment by which all sewers could be inspected throughout their length. The CCTV inspection era was upon us. Unfortunately, we would have to wait many years for camera technology to catch up with demand.

Early in the 1900s, Kodak's invention spurred many industries. By 1930 the cinematography industry it was the period of the silent era. Thomas Edison's industry was moving pictures; the rapid playing in succession of still shots. Lacking in both style and form the industry was haphazard but the primitive art of recording mankind for both leaving a legacy and a form of entertainment would give the collection system inspector the tools it required to create a solid footing and form an industry unto itself. This gave the industry the technology it required to view a pipe its entire length. It would however remain entirely based on emulsion and its cinematography methods are several more decades.

In 1926 Philo Farnsworth and Vladimir Zworkin simultaneously designed a camera, which utilised image pickup and sensing technique. Zworkins' design focused an image through a lens onto an array of photoelectric cells coating the end of a tube. The electrical image formed by the cells would be scanned line by line by an electron beam, and transmitted to a Cathode Ray Tube or CRT. Hence we are familiar with the term CRT today. Conversely, Farnsworths' image dissector device used an anode finger to scan the picture.

Figure 4.The 1927 version of Farnsworth's image dissector. He received a patent for the image dissector in 1930, and successfully defended that patent against Vladimir Zworykin and David Sarnoff. Courtesy: Smithsonian Institution. Source: http://www.ieee-virtual-museum.org/collection

This was a pencil sized tube with an aperture at the top. Magnetic coils sprayed the electrons omitted from the electrical image left to right and line by line onto the aperture where they became an electric current. Farnsworths' device worked pretty well, although could not produce an image serious amounts of light were required for operation. It was however, the beginning of video collection as we know it today. Zworkin and Farnsworth's devices then transmitted the current to a cathode ray tube, which recreated the image by scanning onto a fluorescent surface. Zworkin and the vice president of RCA, David Sarnoff visited the laboratory of Farnsworth and downplayed the importance of Farnsworths experiments and Farnsworths services, saying" there is nothing here that we will need". RCA worked with Zworkin and together they ensured that RCA would control and dominate the television industry for the foreseeable future. In 1934, RCA, demonstrated its' "Iconoscope", a design, very similar to Farnsworths image dissector and the patent wars begun. Through years of turmoil, RCA was compelled to pay royalties to Farnsworth, but truly the design started by Farnsworth had been left behind, only the concept of capturing video line by line in an array and the transmission sequence remained. By the time World War II began, Farnsworth realised that the real money was in TV commercials and being a businessmen, not an inventor in his laboratory. With his patent about to expire he reluctantly sold his company to RCA in 1949. Now RCA truly controlled and dominated the television industry.

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The boiler manufacturer searched the available technologies and found that towards the end of the Second World War, CCTV had been used aboard naval ships for remote viewing. A search of patents revealed that Philo Farnsworth had been issued a patent on an image dissector television pickup tube. The boiler manufacturer purchased the rights and began manufacturing remote CCTV gauge viewing systems using the Farnsworth design. These cameras were very large, heavy, had 200-line resolution, bad distortion and required a lot of light and power.

RCA continued to dominate the marketplace for numerous years. The consumer market was however demanding the use of colour television to keep up with demand with the ever popular colour cinema movies. RCA was forced to accelerate research on electronic colour television well before the market for black and white had been saturated. Under the direction of Paul Schnitzler the challenge was to mechanically align three vidicon images with three colour lenses thereby creating the world's first colour electronic camera. RCA set about this with 3-D sectioning and with the support of Sandoff, RCA retained its rightful place as the leader of the industry. A high proportion of the lab staff worked day and night for six months in the initial effort to prepare a working system in late 1949, and the work continued through the early 1950s. This color system used a high-speed wheel three times the size of the screen image. In February 1953 the Federal Communications Commission adopted the RCA-based recommendation of the National Television Standards Committee for electronic color television. This analog standard which is compatible with the earlier black and white system remains in effect today. The images were produced still using the vidicon and newvicon tube assemblies for the collection of the image from the lens.

Figure 5. **8844 2/3" Vidicon**
Source: www.aade.com/tubepedia/ 1collection/tinycamera.jpg

In the early 1950's the RCA Corporation commercially introduced the vidicon imaging tube. This now allowed the development of smaller (5" diameter) cameras that could fit in an 8" and larger pipeline. Again, the power generation industry began purchasing the cameras. They were built into a waterproof housing and used to inspect water intake and discharge lines in the power plants. As municipal governments owned many of the power utilities, their wastewater department would see the power plant inspections and they began to borrow the cameras to check their sewer problems. These cameras were smaller and had better resolution; but were more fragile and had a lot of electronic noise when moved over debris or joints.

In 1963, a contractor and a major chemical manufacturer were asked by the federal government to develop a method to quickly and economically seal ground water infiltration in sewers. From this research, two part pipeline chemical grouting was developed. However, to test and seal a joint required a modified pipe plug and the ability to correctly position this packer. The modified plug came to be called a chemical sealing packer. A chemical sealing packer looked like a pneumatic pipe plug except it had sealing chambers at each end and a void area in the centre where the two chemicals were injected under pressure. The operator had to place the packer on the joint in order to seal it, and therefore had to be able to see inside of the pipeline in order to position the unit correctly. Now the contractor began purchasing cameras from the boiler makers and started using them in the sealing of waste water lines. City crews again seeing the pipeline CCTV became interested in this market and the contractor began marketing CCTV wastewater inspection systems to wastewater utilities. In 1964 the CCTV equipment business was spun off as a separate company.

The earliest products involved vidicon and newvicon tube assemblies. These products were large and were only able to fit in 8" and larger sewer lines. They often were made heavy to protect their delicate circuitry that they were difficult to pull through the lines and the term PIG and PIGGING quickly became associated with their use. The early vidicon cameras were able to deliver 325 lines resolution and required 10 lux or more of light to produce a picture. One lux is equivalent to 1 candle directed 1 meter towards the pickup device. These cameras were still of course black and white.

Figure 6.Lowering early inspection camera
Source: Pipe Recon Services, Surrey, BC.

Figure 7.Early inspection camera, in 36" Trunk line
Source: Pipe Recon Services, Surrey, BC.

Eventually color was demanded in the cinematic industry and of course the vidicon and newvicon tubes in later years produced color photos, although grainy. The camera in the photo shown encapsulated a movie camera allowed the unit to be dragged through the pipe for inspection, in this case the inspection of a pipeline tunneled under a mountain - 36" dia. approx. 1 mile long - VCR mounted in a waterproof container connected to an axial view camera - battery operated - winched through and videotape recovered and viewed upon retrieval - two shots of equipment being readied at tunnel entrance and one photo of the carrier with external lights and camera at inspection end - wheels all around in case it tipped over.

The introduction of CCD or Charge Coupled Device technology in the early 1970s' allowed many changes in the manufacture of cameras. The size and the weight of the units was the most important breakthrough for these devices. The CCD was originally created as a form of memory, but proved to be much more useful as an image sensor. In contrast to the earlier tube cameras, the development of the CCD allowed the industry to reduce the size of the cameras and thereby fit into smaller pipes than ever before. The CCD uses a small piece of silicon rather than an image dissector to receive the incoming light. This is a solid state device which splits the image into tens of thousands of pixels. Each pixel is a photocell and then uses a series of sliding arrays or registers, much like an abacus to move the data in a serial data stream to be reconstructed at the other end after transmission, or rather at the image display screen, or CRT.

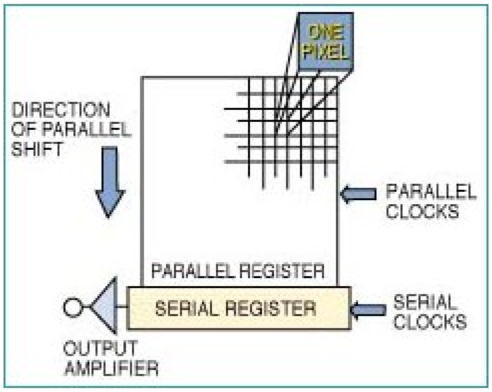

Figure 8. Source: http://www.sensorsmag.com/articles/0198/cc0198/main.shtml

This fundamentally has not changed in concept in today's CRT or LCD monitors from the original fluorescent units which we spoke of earlier. These photocells are not simply on or off. They operate on a time limit, much like when exposing film. Effectively the longer the light is allowed to be on the individual photocell then the brighter the image for this pixel or section of the end picture will be. This effectively allows multiple shades of grey to be created. Once again, similar to the earlier RCA design, colour is accomplished by merging data taken simultaneously by groups of adjacent pixels through red, green and blue filters.

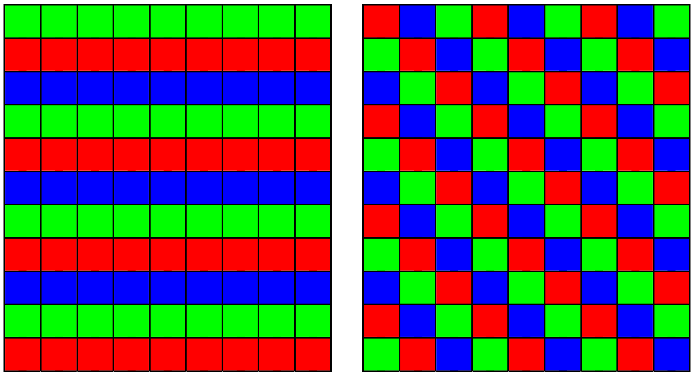

Figure 9. CCD design

There were two designs utilized, one created a checkerboard effect where pixels were aligned in rows of three with different colour filters on each. The other used a multiple chip prism so it could separate colour channels directly and simultaneously in adjacent pixels. Most importantly for our purposes the advent of CCD technology allowed smaller, more durable, less expensive and better quality cameras. The actual image pick up device in today's sewer CCTV units are ¼" and 1/3" square and produce in excess of 400 lines of horizontal resolution. When you calculate the color the calculation would incorporate 1200 lines of pixels to account for the rows of our three primary colours which then will be merged into our colour picture. Each row on a CCD will have 2-300 lines of vertical resolution and therefore in the category of 360,000 individual pixels, or photocell pieces of data which will be used in perfect harmony to recreate our image at the monitor and provide the user with our valuable CCTV data. Add that each image is refreshed 30 times per second (referred to as the frame rate) and you can see that the data transfer, manipulation and reconstruction are truly a staggering mathematical feat.

Early vidicon and newvicon tubes created our industry while modern day advances in CCTV technologies allow our industry to grow at staggering rates. Cameras which used to be the size of your thigh now are more rugged, waterproof, light sensitive and fit in the palm of your hand. These cameras have more features than ever before and fit in more places than ever before. Even the smallest cameras which are for lateral inspections may have self levelling options and sondes built in for locating the device above the ground. They also may be injected into laterals from a mainline launcher instead of from the easier to access clean-out at the property line. Today's mainline inspection camera resolution is so good that camera manufacturers have had to spend time and energy to educate the end customer as to how significant a problem really is. To coin a phrase from your car side mirrors "objects may appear bigger than they really are." With greater resolution, fewer light requirements, we now add even more electronics with automatic iris and focus controls and even add the ability to zoom in on objects which we could not get close enough to view due to debris in earlier models.

Now that we had created "the perfect camera", lets take a look at the evolution of the method for traversing or moving through the pipe. We were still pulling the units through the line manually after flushing the line and drawing a string to drag our camera through.

Figure 10. Hand winch skid mounted camera
Source: Cues archival history

This method of traversing the pipe was used for many years and would be familiar to many of you here today, this method of inspection was relatively effective and supported the CCTV industry for 30 odd years. The typical workday would allow the inspection of a ½ dozen lines but dead end lines or lines which were blocked or collapsed, were impossible to inspect. Early inspections did not offer the convenience of a slipring assembly on the cable reel and therefore before inspection the operator would lay all the cable out in columns before start of inspection to allow the cable to be feed into the line without disruption to the video. Today slipring assemblies are used to allow continuous operation without the need for this cumbersome cable management technique.

Figure 11. Early Inspection Cable arrangement
Source: Pipe Recon Services, Surrey, BC.

Now you would have sliprings to allow the cable to be feed into the line, and equipment was still dragged through using hand winches with drag lines.

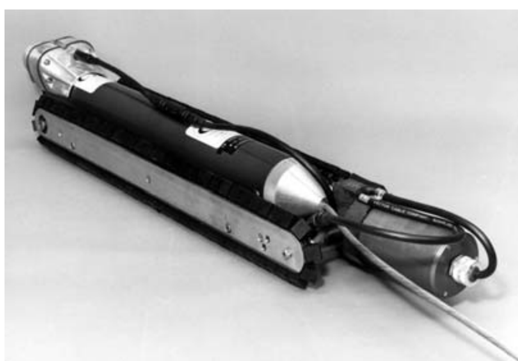

Figure 12. Early long Powertrac tractor
Source: Cues archival history

Today every truck is running with crawlers instead of drag lines. These crawlers resemble small bulldozers or self propelled wagons. They allow faster setups, single truck inspections and most importantly the ability to complete dead end inspections and the inspection of lines which had blockages or collapses. Crawlers allow the operator to inspect a line up to a line blockage and then retract and re-enter from the end manhole. Crawlers also have advanced over the course of the last 20 years, although not at the staggering level as the cameras themselves. Crawlers started as a primitive slab of metal, a wheelchair motor and a camera thrown on top of the unit. The crawler motor created a lot of electrical noise which interfered with the video signal. This was however well worth the increase in production. We no longer needed the flusher truck to thread the line for us. We were now at 8-10 inspections with a single crew and truck. Improvement in motor technology, transmission and electronic filtering has all been implemented with today's crawlers.

Figure 13.Source: www.pearpoint.com

Today's crawlers offer variable speed and multiple torque options including neutral for fast removal of equipment at end of inspection at far manhole. Crawlers are more streamlined and cameras have sections of the crawlers made to conform to their exact dimensions. Today's cameras fit in their mating crawlers like a pair of worn in shoes. Fit and function were a perfect match. Gone are the days where cables would get in the way and roll your equipment over in mid-line. To stay are the days where our cameras optics are better than the human eye and our crawlers are strong enough to pull a grown man across the floor. What will the future bear? Surely, smaller cameras and more options on our crawlers. More applications for our sewer line equipment. Conduit inspections in electrical installations are becoming commonplace.

Today's cameras are now incorporating CMOS in lieu of the CCD technology. CMOS is an acronym for Complementary Metal Oxide Semiconductor. The main advantage of the CMOS technology is the lower power dissipation. In the camera spectrum, CCD vs. CMOS wars, the CCD transfers each charge packet sequentially to a common output structure, whereas the CMOS imager the conversion takes place in each pixel simultaneously. CMOS technologies may allow faster response time, shuttering control and anti blooming, although we are still too early in these technologies to see any significant changes in our industry due to these improvements. In our CCTV collection system industry, technologies are emerging such as sonar for viewing under the water, thermal imaging for viewing outside the pipe, and x-ray for viewing inside the wall of the pipe. These technologies are on the cutting edge. Companies now offer inclinometers to provide a graph of the perfect grade versus the actual grade of the inspected pipe and pipe profiling is beginning to take hold. Profiling allows the user to create a 3-d rendering of the pipeline and see where it is deformed or under capacity. Profiling allows the measurement of the exact diameter of the pipe continually throughout the line. If used before and after installation of a liner, it will allow the measurement or confirmation of the thickness of an installed liner. Measurement of a line before choosing a lining process ensures that the liner is the correct specification so that costly installation errors due to incorrect selection of materials or process may be eliminated.

So the sky is again the limit as to where our CCTV technology will bring our industry. Will we be wireless, transmitting directly from satellites and viewing our sewer lines live at city hall as they are inspected? Not far behind is CAT scanning and bio testing? How about a camera which will take samples of chemical spills in the water and provide analysis of the water and report on the damage to be created by the introduced alien substance in the sewer line.

The beginning of our industry was totally unregulated where now GASB34 and CMOM not only regulate how a line is to be inspected, but how the data received is to be recorded and stored. These standards create storage techniques so cities may share information and certified operators ensure that everyone is speaking the same language. Our regulations will provide the tools to ensure that our history remains history and that our future remains bright. CCTV in the dark ages of silent films emerges into the light of the 21st century as a tool to ensure clean drinking water for the American consumer. As our most valuable resource of clean water dwindles our cutting edge tools will be used to ensure less infiltration so we spend less time cleaning fresh rainwater and more time, energy and money cleaning up our utilities so that our future generations will have the most important resource: water. Oil may become scarce, we need to be sure to remember that we will live without oil; we will not find an alternate source of water. So as we leave today, let's remember that "there's' gold in them there pipes, so lets' go do some digging".

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