



Presentation and demonstration of the Cyclops Camera by Terry Walker

Interviewed by:
Dag Spicer

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Walker: I'm Terry Walker and I'm here today to talk about how I became an engineer and how this resulted in the creation ... the invention of the Cyclops cameras, which were the first products of Cromemco. So in early history I always had an interest in electrical and scientific things and a statement might be to say, "How did the Cyclops come into being?" and the answer is, "My father caused it to happen." I will show you how.

Walker: At age five, this was an interesting item [holding electrical wire], an electrical extension cord, because wall outlets had mystical energy in them and you could plug this in the wall outlet and the energy would appear at the other end. How did that happen? Don't know but age five that's a good mystery. And my parents had several old extension cords lying around the house and this ... we were living in an old farm house out in an orange farm down in [the] Rio Grande Valley and so they said well, I could play with those things as long as I didn't plug them into the wall outlet. So I did that for a while and then ... and they were in pretty decrepit state with the insulation coming off the wires, and one of them this end had gotten smashed and of course those were made out of Bakelite in those days so they crumbled very easily and so there was just a bunch of metal pieces here that all stuck together.

So I had these things all plugged together one day and then I left the room and then there was a commotion and I went back in the room and there were sparks and smoke flying around and lots of action and people yelling and stuff. And it turned out my one-year-old brother had plugged it into the wall <laughs> so he caused a short circuit and that caused quite an experience so no more extension cords and after that it had to be something that was simpler. I did get a electric train around those days and electric trains being what they are there's voltage on the tracks and in those days tinsel on TV ... Christmas trees was made out of lead foil, very thin lead foil like a fuse, and you could lay it across the train tracks and nothing would happen but when the train ran over it, it would make a good connection and blow the foil in half so you'd get a little pop.

So that was my next electrical experiment, but then my father was an Oklahoma farm boy and he grew up with mechanical and electrical things, and he had been in the military in World War II as a night fighter trainer ... instructor and after the war he went to ... we were on this orange farm and on ... once a month he would go up to the Dallas Naval Air Station to fly planes; he eventually learned to fly jet planes, which was a big deal. And since there were radio shops there and I was interested in electrical things he would get stuff from them and so one of the things he did ... I had been messing around for a while with flashlight bulbs and batteries so here's a flashlight bulb. I bought this one recently, it's not 60 years old, and a battery and if you take a flashlight bulb and a wire and a battery you can stick it together if I can do it ... lost the bulb; these things are too slippery, butterfingers ... there ... magic happens. How does it happen? So that was an interesting thing.

So I was messing around with these things around age six and at age seven Dad went by the radio shop in Dallas and he got them to put some wires on a flashlight bulb so now I had a flashlight bulb with wires

and it was easier to play with; you could just do the wires like that and it would light up. So there is a light bulb and a battery and that was an interesting thing, but then we got to taking bunches of these and sticking them together with lots of batteries and doing things like that so I'm going to do a little demonstration here to demonstrate what we did. Now you just saw this bulb is round and it lights up. I have another one here with a bulb that's a little hard to see but it's pointy, and so if I take this one and put it on it lights up the same. All right. All that's interesting but then we're messing around and we say, "Okay. Suppose we put two light bulbs in series and stick them on the battery." Well, you'd say, "Well, probably each bulb would light up halfway." So here's my two bulbs and I'm going to put them this way so here's one. I'll stick it on the table and here's my pointy bulb and I'll stick it on the table. Now either one of these you can light up with the battery so there's the round one, there's the pointy one, but if I do an experiment where the two bulbs are in series ... now you can see they're in series ... and I hook it like this only the pointy one lights up; they're not sharing equally. Well, now that's a mystery; that's a good science project for a seven-year-old. Why would that happen?

And then really to cap it all off I got another light bulb and another battery and made this experience even more complicated so now we have three light bulbs ... get rid of that one ... I have a round one, a pointy one and a round one, and they all have one terminal tied together and then I have three wires left. So if I take my battery and I put it like that as before the pointy one lights up. All right. We've seen that. Okay, but now I can take another battery and mash it together maybe if I'm good. Okay. Now here's the third light bulb. Watch what happens. The two round ones light up and the pointy one turns off. Now this is a big mystery; this is real science-fair action because I'm adding energy to the circuit and yet the light bulb stops lighting up so this is a real mystery, and so to show what we did a little circuit, the first circuit, a round or a pointy light bulb, hook it to a battery, they all light up the same. If I put the two light bulbs in series, the pointy one lights up; the round one is dark. Why? Don't know. Okay.

And then if I take three light bulbs and two batteries and hook it this is the circuit I ended up with so here we had the original two, the pointy one and the round one in series, one battery, and the round one is connected this way with another battery, another cell, and the two round lights light up and the pointy one is dark. That is a problem that is actually not easy to solve and I didn't find out the answer until I was working on my degree in electrical engineering. And so trying to find out why this effect happened was why I was very interested in electrical engineering and all things electronic. That's the bottom line on the story.

So Dad had got me involved with messing with batteries and light bulbs and stuff and all of a sudden this mystery showed up, and at the time that it was done it was not this convenient. We didn't have things well arranged and it just sort of happened by accident and then we never could get it to do it again. You know how that goes; that's science. So it was a long time before I finally figured out what really happened. What's happening here ... I'll tell you the truth ... is these two cells each generates one and a half volts and we have two light bulbs in series so the middle of this string ... since these two bulbs are identical the middle of this string if there was no pointy light bulb here this voltage would be the same as this voltage

so if you hang something between them nothing happens; there's no power for that extra light bulb. It's a wheatstone bridge; that's what it is.

Walker: Along around age eight or so, moving up the electrical ladder, I made a crystal radio and I had a galena crystal, which is here mounted in lead. I don't have the original of course so this is a picture of a so-called "cat whisker" detector. The cat whisker is right here and you use the knob and you move it around on the surface of this crystal and it's a crude semiconductor and you can make it rectify radio signals and therefore recover the sound from the ordinary AM broadcast stations. So I had crystal radios and messed around with that and so I spent most of the next years of my life getting old radios and tearing them up to find out what was inside them and how they worked and take everything apart including taking the capacitors apart, taking the resistors apart, smash the tubes, look inside the vacuum tubes, the whole thing.

Okay. Fortunately, I didn't do anything that was really deadly and then ... so up until about age 12 all I did was tear things up, and then about age 12 something happened. Dad made me a little workshop and he bought me one of these, a soldering iron and some solder; now I could make things. So this was a new revelation so now I could get parts out of old radios or TVs and make things so that was a big thing so that started around the sixth grade, and at the same time period I was ... had run across radio amateurs. There was one who lived a couple of blocks from where I lived who was retired; he looked like an ancient codger but I think he was probably not any older than I am now ... <laughs> I was only 12 ... and he had lots of interesting stuff in his shack that he got war surplus and so I found catalogs for war surplus places and things like that and I also bought a very important technical manual ...oh, there's the soldering iron ... "Radio Receiving Tube Manual," bought one of these from a local supplier, and this was a new world of information because I could now take radio tubes and look them up in it. You could find the technical numbers and data on the tube, curves of how it worked. They had circuits all worked out for you so you just looked up the values of the resistors and the capacitors and they even had examples like hi-fi amplifiers so this was a great store of knowledge which I used in the next time period.

And then one of the radio servicemen that I talked to around 1957 ... I walked in his shop one day and I was asking him questions, lots of questions; I always asked lots of questions. And he said, "Here. Take this and read it," "Radio Amateur's Handbook." Now that is a marvel. I don't have the exact issue; this is a similar issue. You can see it's a very thick tome and it goes all the way from saying what a resistor is to how to build transmitters and receivers and it has lots of technical data in the back of it for how vacuum tubes work and stuff and then it has advertisements for the latest hot stuff for radio equipment. So that was quite a revelation and I studied that book for years to the point that ... you saw how it was ... it has a nice binding and it's really well glued with the pages all in signatures and yet by three or four years later the cover had fallen off; the binding was falling apart; pages were falling out; it really got used. I eventually bought the one that you see here at the library sale in Palo Alto just a few years ago.

Walker: So then given all of that information now I started designing and building my own stuff and also something that I did was to collect things to make things with. Now this was a very popular television set, it was called an RCA chassis 630 that came out in 1946, and a lot of people had bought these but the picture tube was only ten inches in diameter, round, and by the middle to late '50s that we're in now, '57, you could buy a nice 17-inch rectangular black and white set so people wanted those instead. So these things were all getting just thrown in the junk literally and you- you'd drive down the street and you'd just find one sitting by the curb waiting for the garbage men so you'd pick it up and take it home because inside it has this chassis and it has all different sizes of vacuum tubes on it and coils and a humongous power transformer and high-voltage stuff. You could make anything with this so I picked up these things and took them apart and used the parts to make things, and this just shows ... the bottom of it is just stuffed full of little parts and stuff so you take all the little parts out where you have several of these chassis lying around and you're making a circuit; "Oh, I need a certain-size capacitor." You just go to one of these chassis and say, "Where is that capacitor? That one. Okay," and you rip it out and use it. So that was an exciting time for me and around age 13 I started doing high-school science-fair projects; every year I sort of lived for the science fair, which would be sometime in the early spring, and I did different projects.

The first year I did a simple cloud chamber, oh, okay, science, not much electronics. The next year I got a local sign person to make up some tubes for me; they were straight tubes and they had different colors of phosphor tube in them. Now the interesting trick was you could make tubes that were identical; they had the same segments in them. I had about a half a dozen segments of different kinds and you fill one tube with argon and mercury and you fill the other tube with pure neon. Now when people talk about neon signs you realize that actually only the sort of garish red is pure neon; all the others are done with a tube that contains mercury and a phosphor. So I made this up for the science fair and the result was a little unexpected. You would think well, the neon's not active; it doesn't make ultraviolet so all the phosphors in there will just glow orangish-red. One of them actually lit up purple because of something that the neon was radiating that was not ultraviolet, it was something else, and so that made an interesting science fair. And then the next year we got a hold of a transistor, a little-bitty transistor, and of course transistors are highly temperature sensitive so a friend and I made an oscillator with it with a little hearing aid battery and you could stick it on a small animal and it would measure the temperature because when the animal's temperature changed the frequency of the oscillator would change and we used a radio to pick up the sound from the oscillator and so that was fun.

Walker: But then around 1959 I discovered the government printing office and ... oh, that's all the tubes in that chassis ... and they put out books like this so here's "Radar System Fundamentals," the copy I bought from ... in '59 from the government printing office. And you could go through these books and they had a lot of things in them like how you build a radar and all the tube circuitry that goes with it, and then I got another one called "Radar Electronic Fundamentals." That was even better ... that's this one ... because you go through it and it has a lot of stuff but there is the complete schematic for an oscilloscope that was popular at that time. Now these parts in here, with the exception of the cathode ray tube, everything else comes out of a TV set so I started collecting all the parts and looking at how these circuits worked and I sort of redesigned it and made something of my own so ... let me see here ... okay ... I'm not

sure what we have ... there it is. So there is a steel chassis with the circuitry parts on it and I am busy putting a cage over the high-voltage section. It wasn't really needed, I was the only person who would stick a finger in it, but a newspaper writer ... a local newspaper had heard that I did this kind of stuff and they came out and shot this picture; they were going to use it for an article in the magazine ... in the newspaper about science fair projects, and so there I am and that's the only picture I could find of me in that time period.

And then later on I studied for and got a amateur radio license and amateur radio in a certain way was expensive; you needed transmitters and receivers and complicated equipment, hard to make. And I found out at that time from the ham guys there were these sources that you could ... here's one that was in Sacramento in California. Oh, I was in Texas and I could mail order things from these people and they had all these hunks of stuff that you take it apart; you get parts. Here was another one that was in Massachusetts and this was the granddaddy of all of them that everybody got stuff from; you could get all kinds of things. In an article that Barry Gilbert wrote about his young days building stuff, he actually bought this item right here, the radar indicator, and he made an oscilloscope out of it; he mentioned that and it was this kind so there it is. I could have bought one. Of course I didn't know he had bought one and he was in England and so here they have it, receivers, transmitters. These were what were called command receivers, command transmitters; they were used in all of the B-29 and the B-17 bombers and things like that in all of World War II. And the crazy thing about this stuff is that the government ... the U.S. government was concerned about how high their losses were going to be during the war so they made lots of spares and at the end of World War II there were literally huge warehouses sitting in England full of this stuff, so much of it that the English took to piling it into dump trucks and backing up to old coal mines and just pouring it in. Ugh, terrible to think of that but that's what they did.

Walker: So then a little later on I was ... I attended college at a local junior college and we went on a trip to Texas A&M and I found this book, "Microwaves." Now microwaves are a very interesting thing and I didn't know the theory of how to work out all the complicated waveguide and microwave stuff, the mathematics, but I could sure use all the formulas and tables that were in the book to make things so I did and I started making microwave projects. And eventually as a undergraduate working on my engineering degree I did learn how to calculate the theory of waveguides and it's not easy, [it's] complicated mathematics, and finally attending the ... undergraduate I learned network theory and network theory told me why the little lamp gizmo works the way it does so then I could actually write out the algebra and solve the problem and know why it did what it did.

And also after I got my bachelor's degree I worked at Texas Instruments for four years in the government products division and before doing that full time for several summers I worked under what they called a summer development program. So I was up in Dallas by myself for the summer, nothing to do but work and play. Well, the only play I had ... or was interested in was electronics so I would spend four hours every night back at my apartment just building something, and the most complicated thing I built during that time was a spectrum analyzer. This was actually originally a radar set that I had bought surplus when I was in high school and I took all the radar stuff out except the waveguide stuff because I was going to

use this as a receiver for 10 GHz spectrum stuff, and then I put a bunch of circuitry inside so there's a cathode ray tube and there's some waveguide and there's a panel in the back with a bunch of tubes on it and more stuff. From the other side, you can see there's a microwave klystron in here so that I have a local oscillator for a receiver and that shows the ... this was a panel out of an old Zenith TV where I had taken all the circuitry off of it and then rewired it with my own design to do whatever I needed to do to make this spectrum analyzer work.

So that was the kind of construction I did and since I was at TI and we were now into transistors some of the circuitry was actually built with transistors and just for fun some neon light bulbs ... just got to have ... I could have used high-voltage Zener diodes but now I used neon light bulbs so that was it. And during the time at TI I worked on designing new hardware, sort of like design research, for the guidance computer that was used in the Shrike missile so in '65 TI had come out with a missile; this was a Shrike missile. It was used for attacking radar sites in Vietnam; they used a lot of them. And there was a seeker on the front that could pick up the 3 GHz signal from the radar site and then a guidance computer inside the next section, actually this whole section here, and then a warhead and then a rocket motor, and they would just drop this thing from an airplane, launch it and it would home in on a radar station and just blow up the antenna so the radar didn't work anymore. So that was the last stuff I did there and then I came to Stanford to work on getting a PhD.

Okay. So while I was working at TI around 1971 my wife said, "If you ever want to get your doctorate degree, you better do it now." I had been working on a doctorate degree when I was at University of Texas in Austin but that got interrupted by the Vietnam War 'cause in 1968 when I went to TI to work ... for summer work I sent my yearly letter to the draft board and they sent me back a different letter that said, "You are now 1-A. Please report for your medical examination" <laughs> and that was not a good result. So fortunately I was working in the government products division making that Shrike missile that I showed you and the Navy thought I was doing work that was much more valuable to them if I was in Dallas than if I was in Vietnam so it went all the way to Washington but I ended up with a deferment for doing my work at TI. So in '71 there was an article in "IEEE Spectrum" about the best schools for doctorate in EE and of the top ten schools UT Austin was number ten and all the schools above number ten were on the East Coast where there was ice and snow except for Stanford. So we came out to California and toured around and talked to professors in various schools and I eventually found a project at Stanford with a Dr. Meindl that was just starting National Institutes of Health, a very well-funded project for doing research on ultrasonic stuff, and this was in the days before ultrasonic imaging machines existed so we were doing the very basic research on how do you use ultrasound to make some kind of picture of the inside of the human body.

And so as a result I was able to get admission to Stanford starting in the fall of 1972 because I had a lot of industrial experience on building exactly the kind of stuff that we needed for the ultrasound project, all the electronics and things. So I started that and that was associated with the integrated circuit laboratory at Stanford so I learned a lot about making integrated circuits. There was another ongoing project there at Stanford called the Optacon and for the Optacon they needed an area image sensor, a small one, and it

was made in the IC lab using an array of diodes on one silicon chip so it was rather coarse but still an integrated circuit with ... oh, I don't know ... about 40 or 50 diodes on it, something like that. And sometime before 1974 I had been taking a lot of courses and I saw an advertisement in one of the electronics magazines for a new AMI memory chip called an S4006, and the interesting thing about that chip was it was not like this.

Intel had come out with the 1103 chip a few years before ... it was very popular for making memory for computers ... and the actual memory is in these four rectangles that you see located around the chip and in between is circuitry for providing row and column signals for access to a memory so when you get a signal from a certain place here and it intersects with a signal from here that memory chip cell is the one that actually gets used; that memory location gets accessed. Well, this is a dynamic memory chip, which means that the data is actually stored as charge on a capacitor, voltage, and voltage decays with time. You had to periodically refresh them every couple of milliseconds; after about sixty to a hundred milliseconds the voltage would completely decay away. And also I knew from my work at Stanford that if you shone light on it, it would decay away faster because the light would create stray charges in the circuit and cause the capacitors to discharge.

In contrast, so I found out in '75 that a fellow student at the Stanford IC Lab was there as a co-op student and he worked at AMI as a MOS circuit designer, and I asked him about the memory chip, the S4006, and he said, oh, yeah, he could get me a sample so he got me a sample, he got the data sheet and some other information I'll show you in a few minutes. So I got the sample and I took the top off of it because in those days an integrated circuit as often as not was actually in a ceramic package ... you can see this is ceramic ... with a metal lid that covered where the IC actually was. So I took the metal lid off of the package rather crudely, I used a hammer and a knife to do it, and presto, the memory section in the chip is a square; all the control electronics is along the edge on two edges.

Now this memory chip was what was called a pseudo-static memory chip, which meant that you could treat it like a static memory and whenever you sent a command for a certain column and a certain row the state of that cell in the memory would be sent out of the chip to whatever wanted to read that location. And you could do this multiple times but the cell was not automatically refreshed when you accessed it for the data and that made the operation twice as fast, which was a big selling point, but sooner or later you had to refresh the data or it would evaporate so ... because it's a dynamic memory.

So I made a good picture of it. This is a picture I made recently of the die so you can see it better; there's the sensitive area. One cell in here is about that big; it's 32 by 32 so there's 1024 cells in here in a square array and you can see this one was made by AMI ... there's a little logo at the bottom says AMI; it may be hard to resolve ... and this one in the previous photo that I showed you was in fact the actual sample chip that I got so many years ago and it's still in the camera, which I'll demonstrate for you later. And then in those days you couldn't sell an integrated circuit to a lot of big customers unless there was an alternate source; you had to have a second source to assure them that if you had trouble manufacturing that

integrated circuit they could buy it from the alternate source and get an identical item that would work in their final product. Okay. So AMI made a deal with Mostek, which was in Texas, to be the alternate source for this memory chip and so I also have a picture of an AMI chip; this is also a picture I made recently and it says ... I'm sorry ... Mostek and it says Mostek on the edge over here. And you notice this one is rectangular because they made the circuitry over here a little bigger but the memory array is still the same-size square array and so they probably got the database from AMI and changed the design of this part of the circuit because maybe it would make it more reliable or more producible or some other thing like that.

Okay. And so this was the original data sheet for the memory chip; you can see it was in the ceramic package. It came out in 1972, February of '72. Now I didn't get a hold of it until '74 so theoretically all of this stuff that was done making the Cyclops camera could have been done three years before but I didn't have the information and I didn't have the parts so that's history; that's the way it goes. And the electronic definition of this thing is that it has rows and columns with drivers and a cell matrix and a little bit of other electronics so that you can put data in or get data out. Notice the curious thing: It runs on about five volts and minus twelve volts and they call VDD the minus twelve volts, and usually in modern circuitry VDD is the voltage that's not grounded and this chip actually doesn't have a ground pin on it. The technology used to make this chip, both the Mostek and the AMI versions, is a metal gate PMOS and it has a high threshold and it doesn't have very good current flow. The transistor size, {merge with next paragraph}the critical dimension you call it in the transistor, the so-called gate length, is five microns. Now in a modern IBM computer ... I'm sorry, not IBM ... Intel computer CPU chip it's .02 microns, factor of 250, so there's a huge difference between what was being done here and what's being done now but of course there's a difference of about 40 years too, so technology moves on. And the co-op student looked at the computer terminal ... it was at AMI ... and he drew a copy of the schematic of the inside of the chip; now this is number-one industrial espionage <laughs> but he got me the information for it. Now I didn't do anything with it and in fact it's been sitting in my filing cabinet for 40 years so I don't think anyone cares anymore, but the important thing is that there's the memory cell. And it has one transistor that stores the data on a capacitor and then two transistors that read it out, and attached to that capacitor node is a terminal on a transistor and that's a silicon diffusion and because it's a silicon diffusion it's sensitive to light. And because the read-out circuit goes into the gate of a transistor the readout does not affect the voltage stored on the capacitor when you read the values so you can read it multiple times, the rest of the chip usual sort of logic stuff, not very important.

Okay. And so I designed a simple scan convert ... scan driver for this chip and I built it on one of these plastic proto blocks; you just stick the chips in, you stick wires in, you stick resistors in, so I made a circuit like this which had connections to the memory chip, various supplies and row and column drives and a bunch of counters and then an oscillator at 500 kilohertz and the row and the columns each had a D-to-A converter just made with resistors to go to an oscilloscope. So it would sit there and increment all the way through a row and then it would increment the column once and then it would do the row and then it would increment the column so it would scan through the entire array. And this would only ... what it would do is write the entire memory so that it charged all the capacitors and then it would scan the entire memory displaying the contents. And I discovered that if I ... now I had my chip sitting in the middle of the

block with no lid on it so if I held a little magnifying glass over it I could image the ceiling light on the chip and I could see the picture of that on my oscilloscope where I had the oscilloscope set up as an XY display, so it's plotting the contents of all the memory locations with versus time and it did it fast enough that it looked continuous, the eye didn't see any flicker, but there was no evidence of grey scale activity.

I couldn't adjust the voltages on the chip so that it was responsive to variations in light intensity; it was just either on or off and that's it. So a few days later I redesigned the circuit and I added another counter down here so that it would write the memory chip, setting all the capacitors with a charge, and then it would read it 15 times and so it's repetitively reading without changing the capacitor value. So if you shone light on the chip now how long it took the voltage on the capacitor to discharge depended on how strong the light was so now I had greyscale imaging of a sort, 15 different brightness levels. And so I designed up a complete little circuit with the image sensor, all of the counters, an oscillator, some D-to-A circuits with resistors and outputs for an oscilloscope, and then the data output from the chip going out through a drive amplifier to drive the intensity of the ... an oscilloscope. So now it would write all the cells high and then it would address a location, produce X and Y to plot on the scope, and then whether the cell read as high or low it would turn the beam on or off on the oscilloscope. So every time a cell had discharged it would turn on the scope and make a little dot ... dot, dot, dot, dot, dot, dot, dot, dot, dot ... and you could make an image that way and furthermore it would sit there and scan through the array 15 times, repeating the dots on a similar spot so that if the light was brighter on one spot that spot would get hit by a lot of dots and if it wasn't very bright at all it would only get one or two dots hit so you'd get variations in intensity so I did achieve grey scale operation.

And after optimizing the number of ICs required, which is this design ... oh, first I want to talk about the sensitivity of the chip. The voltage on a capacitor might be represented by the height of this line and if you just ... if you didn't shine any light on the cell the voltage would just stay flat until the next time so nothing would show. If you put a little bit of light on it, it would run down to zero by the time you had read it 15 times and it would show a dot on the scope and if you put a lot more light it would run down sooner and you would get a lot of dots on the scope for that cell. Okay. And I went through and derived the equations, which are sort of messy, and I calculated a little table and found that the amount of intensity shining was different values here from .1-something to about 3 or 4, but the ratio of the ... of these values between one and the next all the way down is relatively constant.

So to get an additional dot you had to have about 30, 40 percent more light and then ... it's like compound interest and it just keeps piling up on you and ... which means that it produces a logarithmic response, which is similar to the eye. So, I did a pencil sketch for making a little circuit board, didn't have computers to do that, no automated layout software or anything. So, I just drew this on a piece of grid paper. I made little dots for where the chip connections are. And I drew wires for where the wires were going to be. And I took that pencil sketch, and I put a piece of clear Mylar on top. And then I used a black tape to draw patterns and little dots for all of the pins where there were going to be holes in the board. So, I made a black pattern.

I made a Xerox of the pattern and marked on it with red, as you see here, checking how all the components fit together on the board. And once that was done, I took the tape thing over to the IC lab. We had a very primitive printed circuit board processing capability. And we made a film from the tape artwork and then made a circuit board. And I stuffed the parts in it. And there's the circuit board. So, now I have the sensor chip. I have all the digital logic. I have a bunch of analog stuff, and output driver, and a couple of light bulbs. Now, what in the world do those light bulbs do? Well if you were to look back at this graph, it takes a certain amount of light to get anything to happen at all. And if you have less light than that, it's just no response. Well, that's very poor sensitivity. And remember, I was buying a lot of World War surplus stuff earlier. And one of the things I had bought was called an iconoscope TV camera. And it was actually made for use in a very early drone airplane. Now, that had to be a big drone because the camera was huge. It was about so square and about this long. It had an iconoscope imaging tube in it. And it had exactly this same problem.

So, they had solved that by putting a little light bulb in the camera mounting behind the iconoscope tube, so it put uniform light on the entire image surface in addition to the light from the lens at the front. So, I did the same thing here and added these two lights on the ... next to the sensor. So, the light would bias up the sensor a little bit to get better sensitivity. And you can see it from an angle here how it looks. So, there's the two lights and the sensor chip. And if you look closely, you see that this sensor chip is sort of crooked in the package, the same as the first one that I showed you that was unpackaged because it's the same chip. Okay so, I put it in a nice box. I put a lens on it. Now, the lens is a monster because I took it off of a sixteen-millimeter movie camera that I bought at the local second-hand store.

But the reason I used that lens is that it had a complete set of adjustments for focus, for light intensities with f-stops, and for zoom, for changing the depth, different locations. So, it was a great lens for that purpose, just bulky. And this ... the circuit board that I showed you, fits exactly behind this front panel, inside the box. And then other stuff is behind it. On the back there ... being an engineer, of course, I did not use RCA jacks or binding posts. I used BNC connectors. And so, this is X, Y, and Z to go to oscilloscope. Power switch, this adjusts the strength of the bias lights. So, you can set the sensitivity. And one time, a long time ago, I had a special oscilloscope that was only used with this camera. And so, I put a connector on here with all the signals on that connector, so I could just have one cable going to that oscilloscope. I don't have that scope any more. I sold it at the flea market. So, inside this thing, you can see the back of the circuit board, tail of the bias light, and just simple bulk power supply, very crude, not regulated. Way overkill, this transformer is probably five times as big as it needs to be. But it was off the shelf. And it was a couple dollars. So, looking at it from the side, you can see there's the sensor. There's the back end of the lens, the bias lights, lots of wires, another view there, opposite end of the circuit board.

Ah, I didn't mention, but when I was first working on this circuit board before I built the box, I was running it on my tabletop workbench. And I had the power transformer hooked up. And it was running off the AC power line. I didn't do a very good job of insulating the AC power line connections. And one day, the AC power line connection accidentally touched one end of the circuit board. And the other end of the circuit

board was thoroughly grounded through the oscilloscope to the ground in ... the safety ground on the outlet. So, all the ICs on the circuit board blew up except the sensor. It wasn't harmed. Who knows why? But even traces on the circuit board disappeared. So, that's why there's a piece of wire soldered across the circuit board there. I put all new ICs in, except for the sensor. And the board ran again. So, fine, good. So, I took this thing in. Now, it was all built.

And I took it into the IC lab and showed it to Roger Melen, whom I worked with. He had gotten his doctorate degree in '72, the same year that I came there. So, he was working as a research associate. I showed it to Roger. And he looked at it, and he said, "I think we can make something of that and sell it." Now, he and Harry Garland had been, for a number of years, making little kits and selling them through articles in *Popular Electronics* magazine. Very seldom did they get a kit that was exciting enough that it would go on the front cover of the magazine. But Roger looked at this and he said, "This is unusual. It's a new thing. There's never been a low cost all solid-state TV camera that anybody could buy, especially an experimenter," because even just the sensor inside would cost you hundreds of dollars from an official company like Reticon. So, I said, "Sure. Let's do that." And so, Roger and Harry formed a company called Cromemco. This was their first product. Harry wrote the article that went in the magazine and shot the pictures and so forth.

{please cut the video here to remove the coughing in the background, and leave these as two separate paragraphs}

This camera is a copy that Harry made for checking everything for the article. And it has a small lens on it from an eight-millimeter movie camera, which is all it needs. And the picture here on the cover is Les Solomon, who was the editor at *Popular Electronics* at the time. And so, they took a picture of him with the camera and stuck it on the cover. And so, he put together a nice article, well written, with a ... there's the schematic and everything again, and the circuit board, and how to put it in the box, how to make the power supply. You can see that his capacitors were silver. Mine were orange. That's life. That's the way it goes. And so, another view again, which looks a lot like the one that I made, except the transformer is straight because the capacitors are smaller, so they fit better. They then ... then in later years ... well, at the same time, they sold a built version of the same little circuit board. You could buy it as a kit for ninety dollars. And that kit would get you the circuit board, all of the ICs that went on it, and the sensor. And you had to provide the rest and build it. So, that was a kit that they sold.

And then ... and that came with the kit, the same schematic from *Popular Electronics*. They also sold the sensor separately. So, here's a datasheet they made for the sensor. And they sold it for about fifty dollars, which was outstanding since I think they probably paid four dollars for the memory chips. And they set up a little production line. And they took the memory chips, which have a steel lid on them, took off the steel lid, put on a clear quartz lid using an epoxy ring, ran it through an oven that sealed it on, and then they sold them that way. And they also provided them for the kits.

Now, an interesting thing happened. When they went to actually mass produce these sensors, they ordered a thousand of them from AMI and put them in the camera. They didn't work. The picture was all scrambled. And the reason was that when AMI (error: Mostek) copied the memory chip, they had changed the way a couple of the address lines worked. So, it scrambled the picture contents. And so, we put a couple of little jumper wires on that circuit board for the camera kit before it actually went out, so you could use either type A or type B sensors. So, the new kind that Mostek had made, which AMI was now selling, was type B. The original one that was in the original prototype was a type A. There aren't very many of those around because AMI had found that the Mostek chips gave better production yield. So, they (AMI) were using the Mostek design instead of their own.

Now, an interesting point about making a silicon sensor like this is that silicon is really best as an infrared device. So, here are some curves. This sort of pointy, squiggly curve is for an ordinary fluorescent light, cool white fluorescent light like in the old days, in the '70s or '80s, which weren't known for really good color rendition or anything. And that kind of light has almost no infrared output. The human eye response is this part, this red part here. But the silicon response is this big hill that goes way over here into what's called near infrared. Tungsten lights, like we're using now for the filming or for other things, ordinary light bulbs when they were still available, have a lot of infrared radiation, a lot more than they have actual visible. And that's why Tungsten lights are so inefficient because most of their energy output, it's there, but you can't see it with a human eye. You can see it with a silicon imaging device.

And the result is that, if you use a Tungsten light to illuminate the object that you look at with the Cyclops camera, it's about ten times more sensitive than if you use a LED light or fluorescent light because that only gives you energy up here. And you're missing all of this sensitivity. Now, around in 1975, for no related reason, one of the comic strips called the "Wizard of Id" came out here: "I have an invention, which should reveal the identity of the lone haranguer, great. It's a picture box, which has an eye. When I open the eye, it retains whatever it sees. What do you call it? Cyclops." So, there we were. We made the newspaper. And there also was an article, this is probably too hard to read. But in one of the electronics magazines, there was an interview article related to the Cyclops camera. Harry took a couple of pictures for the *Popular Electronics* article, but they didn't use them. This was a crescent wrench that he imaged with a Cyclops camera and looking at it on the oscilloscope. {merge with next paragraph part} And this one, okay, can you tell what it is? Any idea? It is a TO-3 power transistor. As I'm holding it here, it's hard for you to see probably. But it's a basic diamond shape metal base with a round top on it. And so, there's the diamond shaped metal base, the round top, a little specular reflection off the round top, the pins, which stick out the bottom, pins, and mounting holes, yeah. When I first saw it, I didn't know what it was either. I had to ask him what it was.

Okay, and a few years ago, there was a fortieth reunion for Cromemco. And so, I got out the Cyclops stuff and got it all working again for October 2015 and set it up to run. So, here is the stuff that we'll look at it in a demo later, an oscilloscope, which displays the Cyclops image, the camera, as you are looking at, and image ... object, an object, not the image. The image is here with a Tungsten light illuminating the object. When I turned this light off it, disappeared from the oscilloscope.

Okay, during the time that the Cyclops camera was being gotten ready for the publication in *Popular Electronics*, this was some months before it actually came out in the magazine, as a final stage of that, Roger went on a trip to New York where it was actually published to visit with the publisher there. And he saw what was going to be on the cover of the next issue of *Popular Electronics* after the Cyclops camera. History people will know it was the MITS Altair computer, a very big thing. And Roger looked at that and said, "Well, I've got to have one of those to play with." So, on the way back to California, he stopped and talked to Ed Roberts at MITS and arranged to get a computer. And while he was at it, he mentioned the Cyclops camera, which was going to be on the previous month's article. And Ed said, "That's a neat thing. I'd like to have it available as a peripheral for the Altair computer, so we can have vision capture for the computer."

And so, when Roger came back to California, he told me. He said, "Let's see if we can make a microcomputer interface for the Cyclops camera so it can be plugged into the Altair computer." So, that's what the Altair Cyclops is all about. As a result, I did some preliminary design work. I first tried to sketch up how I was going to do it if I used CMOS parts because this was going to be a small device that is remotely located from the computer. You don't want it to use a lot of power. It needs to be simple and compact. And so, I was going to do it with some CMOS parts. And I did one design in, when is that, November of '74? And then I did another one in December of '74, slightly different circuitry. And then we got the parts for the Cyclops production run. And they had this funny problem with the image being scrambled. So, I got the datasheet from AMI, the new datasheet now, 1974 datasheet, and discovered that two of the row lines ... column lines had been swapped and inverted. So, it divided the image into four pieces that were in the wrong sequence on the screen. So, I then created a new schematic, which had swap and invert between the counter and the sensor. And I built one up on the little proto-board, and that worked. So, I drew all of this up and divided it into pieces because we were going to use a small box for the Cyclops ... Altair Cyclops.

I couldn't get all the circuitry onto one circuit board in the box. It wouldn't fit because, after all, remember the circuit board has to be sitting so that it's square with the end of the box so that the lens can be right in front of it, so it holds the sensor. So, I made one board that had just the sensor, the address counter, and a little logic on it. Another board had some timing stuff on it. And a third board had the interfaces for the cable for data going to and from the camera and some voltage regulators for providing regulated voltage for the circuitry. So, this was the concept. Here is the actual camera as built. This is the one that we're using today. And you can see the first board is here. The sensor is there right behind the lens, a second board with timing stuff, third board with cable interface and regulators. I can show you how I managed to squeeze three ICs onto the board. So, we have the address counter, the sensor in the middle, and then some extra logic on that board. The timing board has a couple of chips used to make some timers because we're going to send clock pulses to the counter ... to the camera. The clock pulses are going to cause the addresses to increment for the sensor. And it will do that repetitively. That works fine. But we've got to be able to send some commands to the camera also to tell it when to start, when to write to the sensor, when to read it, when to turn the bias lights on and off.

And so, these timer circuits measure the pulses that are coming to the camera. And if they're long pulses instead of short ones, instead of moving the counter, they do other things. And then we have the cable interface for receiving data, the clock pulses coming in, some transistors for sending the data back to the computer, and the two voltage regulators so that you could actually put this camera on the end of a hundred-foot piece of cable and not have any problems because of voltage drop in the cable. It would work just fine. And that was important for industrial applications. So, there it is all buttoned up and sitting on a tripod. And it had to have an interface that went in the computer. And it took a lot of stuff to connect this serial controlled thing with serial data coming back to the computer. So, I ended up with two circuit boards full of TTL ICs. Now, I would point out here, notice there's a lot of space between the ICs. I'll show you that later on some other boards. This board, I laid out again using the Mylar. It has only two layers on it, top and bottom. That's it. And you can see the lines on it are pretty fat. In fact, all of the lines on that are one millimeter wide. That was the width of the tape I used to do it. It was done with a so-called blue and red Mylar sticky tape for the traces. So, there's a second board. And basically, one board handles controlling the camera and generating addresses for DMA in the computer, and the other board handles getting the serial video from the camera and formatting it, and arranging it, and stuffing it into memory in the computer.

So, there's no memory on this board for the image data. It uses the computer's memory to store the image by using direct memory access, or DMA. They drew up some nice schematics for this one. So, this is the first board, which has a lot of counters and DMA stuff, and then the second board, which has the DMA control unit, and the data formatting that goes back to the computer memory, and some I/O port control stuff. So, a simple one-page flier was put out for this. So, it has the camera itself at the top. And then the two control boards, which would plug into an Altair computer. And when the camera ran under software control, it would place an image in a specified area of the Altair computer. And you could then read that using the CPU and do things with it. Sometimes, when you wanted to test a camera, you didn't want to have to haul out a whole computer, and software, and all that stuff. So, I took all of the stuff that was in the original Cyclops camera that was not used in the Altair Cyclops, and I just put it on a separate board, duplicated the address counter. And this I could then connect a camera to it. And as a result, it would output the XYZ signals for an oscilloscope just like the original Cyclops camera did. So, it was easy to test the Altair Cyclops camera, extra stuff, power supply, and stuff for that.

Now, when the Cromemco reunion came up a couple years ago, it was a daunting task to think about trying to get all the circuit boards running in a flaky computer. It takes seven circuit boards all working perfectly to be able to display on the computer display the data that an Altair Cyclops camera puts out. So, what I did instead was I made a small circuit board. This is about four by six inches. And on this circuit board, I put a couple of little power converters. So, the input power is only five volts. But this puts out the plus or minus twelve that the camera runs on. And this is a two thousand byte static memory, so-called dual port memory. So, I can stuff data in one side and read it out from the other side. And it never gets confused. So, I put it in. I take it out. The two locations don't have to be the same. It doesn't matter if they are or not. It still works correctly. And then I took all the digital logic from all those seven boards and stuffed it into a little complex logic device here, which has equivalent of about eight thousand logic gates in it. So, it contains the two boards for the Cyclops camera interface, the two boards for the TV Dazzler,

the equivalent of a CPU card, a RAM memory card, control, and one more (EPROM program memory). Anyway, there's a lot of stuff in there. And then it has D-to-As on the output. And so, now the output can go to a regular computer monitor as we use them today, which is like a VGA format computer monitor with red, green, and blue, video signals. So, that's that thing.

Now, using this and an Altair Cyclops camera, what does it do? Well, that looks really good. I got a letter E on a piece of paper and put it in front of the camera in exactly the right place so that the black bars of the E exactly match the pixel locations in the camera. If you do that, you get a perfect letter E. And that works great. But if you try other things, well, there's a hand. And well, the pixels are thirty-two by thirty-two. But, you know, the hand is not resolving very well. These are individual pixel squares here at different gray levels because the camera does give gray levels. If you move the hand around, it looks a lot better because the eye averages the pixels.

Now, it turns out that because I had extra gates in the gate array, I put in a linear interpolator for two dimensions. So, it takes those same thirty-two by thirty-two pixels and interpolates to sixty-four by sixty-four. Now, you can see the hand much better. There's not actually any new data there. It's still the same original data that came from the Cyclops camera. This just shows what you could do with image processing in the computer if you wanted to do it. Here, I just did it with a logic gate array instead because it was easier. If you put something in front of the camera which has diagonal lines on it like the letter V or the R, you get strange artifacts. You know it sort of goes fast for a while, and then slow for a while, and fast for a while, and slow for a while. And you say, "What's going on here? That should be a nice diagonal line." Well, remember we only had thirty-two by thirty-two. But not only that, this chip was not designed as an image sensor. It was designed for use as a memory. And the result is that when they did the chip layout, the columns and the rows are all mirror images. And the sensitive junction that we're using to sense the ambient light is not in the center of a pixel location. It's towards one edge. So, you get two that are close together, and then a big space, and then two that are close together, and a big space. And that happens in both dimensions. So, that's what's causing this problem here.

But on the other hand, we had a really cheap sensor. So, what do you want? You want really good? You pay hundreds and hundreds of dollars. This was a different set of letters. Now, you see if you get a block letter on there, you don't see that effect. So, it's okay. Now, if the image features are too small, they might be inadequately sampled by the sensor cells. And sometimes, they don't even see them at all here. It doesn't even see it. So, that is one of the application problems of trying to use an image sensor. Even nowadays, you have to match the image sensor you're going to use with the size of the objects you're trying to make pictures of. Now, there was a company that bought the Altair Cyclops cameras. And they used them for an agricultural purpose. They put them on a harvester, which has a wide thing that goes down a whole bunch of rows of asparagus growing out of the ground. Asparagus, you know what asparagus looks like. Okay. And so, they have all these asparagus sticks sticking out in rows. But they're not always right in the middle of the row. Sometimes, they're a little to the left or the right. And they want this harvester to be able to reach out there and cut off that asparagus stick and flick it in the box. And so, they put an Altair Cyclops camera on each row. And all they had to look for was where was that black line

in the middle of the picture. And that told them where to chop and grab to get the asparagus. So, that was a fun thing.

Now, as an exercise, I decided to ... and I did this last year after the Cromemco thing. I decided to see, with modern electronics, how small you could make the Altair Cyclops camera using the same sensor. The only thing here that's original, of course, is the sensor. And you can see here that this particular sensor has a quartz lid on it. That's what causes the outline around here. And I took all of the digital logic that's in the camera and crammed it into a little bitty logic chip, another CPLD, complex gate array. And these are all little surface mount parts and a crystal oscillator and one eight-pin bug. And the backside of the board just has some voltage regulators and a couple of transistors somewhere, oh, just another regulator. Three regulators, that's all it is, and a pot to adjust the bias lights. Bias lights, oh yeah. There's the bias lights now. No more light bulbs, little LEDs, which didn't exist in '75. And this chip has the same connector on it, this board, same connector, same signals, works identical to the original Altair Cyclops camera. So, that was a fun thing to do.

When we did the Altair Cyclops for the Altair computer, there was a problem. The only way you could see what the Altair Cyclops actually saw was a very slow printout on a Teletype. It would sit there and peck out letters with various densities to represent the gray levels on the camera and what it saw. Well, you know, you can imagine it would take some minutes to get one picture. And that made it really hard to adjust the focus and things like that. So, right away when I was designing the Altair Cyclops hardware, I also realized we needed some kind of display. Now, I had a lot of experience with television technology because I'd been repairing television sets for many years by then. And so, I knew exactly what electronic signals you had to have to create a television picture either black and white or color. And so, I told Roger. I said, "Hey, we need a graphic display for the camera." And so, I proposed a design. And the design basically would be able to do either a thirty-two by thirty-two or a sixty-four by sixty-four pixels. So, it worked with the camera or had better resolution and did it in gray scale, black and white, sixteen levels of black and white. So, that wasn't particularly fancy. But I went into the office one day, Roger's office, and was talking to him about the design. And he said, "You know, if we had color, we'd really have something. People would really notice that. Color is so much better than black and white. Just look at color TV sets. They sell better than black and white." And I said, "Oh, color, that's trivial. I know what it takes to do that. All we need is a couple more logic gates, and bang, we have color," and ... because it was actually really easy to generate color signals for the old analog TV standard.

So, I redesigned the circuit so it had color. And because memory was expensive in those days, the circuit was designed so that it would use the memory in the computer to store the image. So, it used direct memory access to fetch the image data from the computer memory. And you could tell it which part of memory to use because these computers had a sixty-four kilobyte address space. And the thirty-two by thirty-two display only needed five hundred and twelve bytes. So, that was half of the memory that came on the basic Altair, which had a thousand twenty-four bytes. So, you could do it. And if you could afford more memory, you could go up to the next level and have a sixty-four by sixty-four display, which would use two thousand bytes, 2K bytes, to display the image or to hold the image. And it would display sixty-

four by sixty-four. So, I built up a wire-wrap prototype of this thing and gave it to Roger because he had the computer. I didn't have a computer. And he plugged it in. And he said, "That really dazzles the eye." And what happened was all the colors on the screen were all going like this all the time, back and forth, wiggle, wiggle, wiggle, wiggle. You'd have a pixel with a color on it. But the edges of the pixel were always jiggly. And he said we should call it the TV Dazzler because it dazzles the eye. And I said, "Oh, well I better fix that problem." So, I changed the logic so that the scanning of the pixels was synchronized to the color subcarrier. So, the color subcarrier data stood still. So, each pixel that it plotted would always get the same phase of color subcarrier so the edges didn't jiggle. And that worked. So, we did a circuit board layout. I don't remember if I did this one or not. I think I did, yes. I actually hand laid this out again using the one-millimeter wide tape, red and blue for top and bottom, two layer circuit board. And one board has mostly analog stuff. You can see there's analog stuff here for the ... D-to-A is for the output and for the color control. And the other board mostly had control ports and hardware for generating addresses and fetching data from the computer.

Now, there was a little aside in here that was important. When you use DMA, you didn't want to use it a hundred percent of the time because then the CPU stops dead. And yet, you don't need it a hundred percent of the time even though you're filling the TV screen because the pixels at thirty-two by thirty-two were six scan lines high on the TV set. So, for the first scan line horizontally, you would read the data from the memory. And for the next five, all you had to do was duplicate that data. And there were only sixty-four pixels. So, located on this board right there is a part called a 3417. It was a sixty-four by four shift register. And it stored the data for one line. It would circulate it around to help fill out the pixel vertically. And then when you went to the next row of pixels, it would take in new data from the DMA unit. That way, the time hit on the CPU was only about fifteen percent. It was less than one sixth because you didn't fetch data during the times when there were no pixels being drawn on the screen. So, that's how the hardware worked. They drew up nice schematics for me on this one. So, there's a bunch of ... well down here, you can see a bunch of gates are hooked up with resistors to make D-to-A converters.

There's the oscillator at the color subcarrier frequency and then some phase shifters. These are really cheap shot phase shifters. They were just done with an inductor, a capacitor, and a pot. And remember, on the top of the analog board, you see there's some little pots here. And there's a variable capacitor. The instructions for the kit builder were after you build it, put it in the computer. You put a test pattern on your TV screen. You turn the capacitor until you get the best looking blue. And then you turn the first pot so you get the best looking green. And then you turn the second pot so you get the best looking red. And that's it. So, there's no precision in this circuit at all. It's just whatever the user wants. So, that circuitry is all going on down here. Here is the MOS memory. You can see it's hooked up in a loop so that it recirculates the data during the horizontal lines. And occasionally, it gets new data in from the bus. And then the other board is just DMA stuff. There's lots of bus connections for sending addresses and control signals and whatnot, all the things that make DMA work.

Well, this was a big deal because it made a color display. It went in a hobbyist computer, and it was the first color display for a hobbyist computer available. This was before the Apple II. So, it was a big deal.

And so, it made another cover article for *Popular Electronics*. So, there it is on the top of a *Popular Electronics*. There are some screenshots taken off a TV monitor of the Game of Life running on a TV set. That's just a small part of the whole image, and then a write up on it. And there I am, first author. I didn't write it, though. Harry wrote it, and all about how to build it, how it works, how to program it, a set of boards, what it looks like, and a pattern. Now, if you run a TV Dazzler, you can put a program pattern into memory, which lights up columns. This is thirty-two by thirty-two. And it had seven dim colors plus black. Black doesn't show. So, here's dim colors. And then it had seven bright colors plus black again. So, it actually had fourteen colors, and you get black twice. Yeah, that's the way it goes. It was a cheap circuit. It didn't cost any logic to do that. And then if you ... and here you can see, of course, the software is incrementing the pixel color code both vertically and horizontally and then likewise at sixty-four by sixty-four. So, yeah, we got colors. That's not very exciting yet. You can also get gray scales. It has sixteen levels of gray scale. But they don't come out real well on the monitor. So, you don't see all sixteen. This is on sixty-four by sixty-four. And one other mode that was in the TV Dazzler was you could interpret each pixel, which has four bits for either sixteen gray levels or sixteen color levels. You can interpret as four independent bits and light up four little spots on the screen. So, now we have a hundred and twenty-eight by a hundred and twenty-eight pixels, but it's only on or off. And you would say, "What would you do with that?" Well, it gives you better resolution for games and stuff. One of the first pieces of software written for the TV Dazzler was one which generated random numbers and plotted them on the screen. And this was called Kaleidoscope. And so, you got symmetric plots of stuff. And it ran dynamically, very quickly. I'll show that to you in a few minutes. So, it was very colorful and mesmerizing.

Later on, I did other graphics interface cards for Cromemco which had more resolution. So, here was when the next card came out. It was called the SDI Super Dazzler. And they put a picture of Einstein sort of bitmapped onto a computer monitor. And later still, the graphics cards got up to the full resolution used in analog television, which is 756 horizontal pixels, 484 vertical pixels, and 24 bits of data per pixel ... 3 bits each, for red, green, and blue ... and that produces beautiful colors. Cromemco put those in some machines that were bought by a company called Colorgraphic Systems, that was in Minnesota (error: Wisconsin), and they programmed it to produce stuff like this, with software. And those machines were used by a lot of local TV stations for doing the weather forecast projection ... background, and everything ... where the weather guy stands there and waves at the... he stands in front of the green screen, really, and the computer projects the weather chart behind him. I think they sold about 400 machines. It was a lot of stuff. A lot of stations were using it.

Okay, so that is all of the TV Dazzler slides. I have some videos I want to show to you, so let me see if I can get those set up.

Now, turn on the mouse. It doesn't work on a white table. Okay. Kill that. Now, these are clips of things running on a TV Dazzler, and I made these videos last year. Now, I did not use an Altair computer. <chuckles> What happened is, there is a S-100 computer enthusiast who lives over on the other side of the bay, by the name of John Monahan, and he designs a lot of boards that go in S-100 computers, but he did not have a TV Dazzler board. And so I designed a clone of the TV Dazzler for him, that would go in

his computers. And everything is on one board, instead of two, and it has extra functions and all kinds of stuff, but it will run the original TV Dazzler software. So I did that here, so let me see if I can get this video to work. Okay, so this is the... what was it called? Kaleidoscope program, running. Now, this program is running 5 times faster than it did in an Altair computer, because it has a 10-megahertz CPU, instead of a 2. So that makes it a little bit more dazzly. But that's an idea of that thing that was done. Now, this is a clip from a game that was written for the TV Dazzler, called Ambush, and the object is that you use a joystick to control where you shoot, and you're shooting at various moving objects on the screen, and when you hit an object, you get a point score. But some of the objects are U.N. trucks, and if you hit a U.N. truck, then you can't shoot for several seconds. <chuckles> And you get penalized. So, here goes this guy. Okay.

<sounds of machine gunfire>

There you can see... oh, we even have sound, but it's hard to pick up. So, there's a tank. Tank's worth 100 points. So that was that particular game running, and it was using the bitmap mode. But always, of course, the granddaddy of games you got to have is Spacewar! So I managed to get the Spacewar! program to run. Now, this was hard, because I had to control two spaceships and hold the camera, all at the same time. But here we go. So, there's two spaceships orbiting around the sun. And then, eventually, one of the spaceships will shoot; I think, this guy. There! He's shooting something. And he hit the other ship, and it blew up. Okay. The Spacewar! program that ran on the Altair was written by some students at MIT. Okay? And here's another shot of the Spacewar! program running. A little bit different orientation, but pretty much the same. And again, this program is running five times the normal speed, because the CPU's fast. It has software timing in it. That Ambush program, incidentally, was not running five times faster. It was the normal speed of the program.

All of the things that I've told you about so far ... the Cyclops, the Altair Cyclops, the TV Dazzler ... that all took place over just a couple of years, while I was a graduate student at Stanford, working on my doctorate degree. So I just worked on these things in the evenings, and I did the Stanford stuff during the day, when I was at Stanford. And it was financially rewarding, so it was a lot of fun. But after those things were done, I continued to do other circuit boards for Cromemco. A lot of them had to do with graphics. As I mentioned, we did various versions of all the different graphics boards. I also did some memory boards. And so I just will show you, briefly, that is a Cromemco card cage ... 20 slots, has 19 circuit boards sitting in it. These are most of the other items which I did. There's probably another dozen or so, some of which didn't go into production. These were all in production.

They just have tags on them. One of the things you had to have to play Spacewar! was, you had to have a joystick. And if you have a joystick, you have to have a way to connect it to the computer. Well, joysticks are analog, and you have pushbuttons for functions.

<woman coughs> {can you cut this event out of the video recording, or just momentarily blank the sound?}

So I made an analog and digital combination I/O board for the Altair computer. This was one of the very early products, right after the TV Dazzler. And this was called the D+7A I/O. It has seven analog channels of output and input, and it has one byte ... which is eight bits ... of digital data output and input. And you can see this is sort of clunky. It had this big connector that went on the top here, that would fit inside the card cage, but it used a standard card edge connector, so it would just plug right on, and people knew how to handle that, in those days. That was really before ribbon cables and stuff became common. And this board was fairly fast. If you sent a command to it, to give you the analog value from an input, it would convert it and give you the answer in, oh, six microseconds, or something like that. And if you sent an output, it didn't have to wait; it would just do it right away. And same with the digital data. Now, when you went to play Spacewar!, you needed joysticks, so Cromemco made up a set of dual joysticks, like that ... four pushbuttons, X and Y analog pots [potentiometers], and the D+7A. So this was your game input kit that you could use to play games on the TV Dazzler, and it's a lot of fun to mess with. You get to banging around on it a lot, though, and you break the handles on these, the buttons get broken off, things like that. I had to glue these joysticks back together before I could take the photograph. <laughs>

Now, one of the other things that I did was, remember, I said the original Altair only came with 1,000 bytes ... one K-byte ... of static memory. And people started writing software, and immediately they wanted more memory. And you couldn't put very many cards in ... the 1,000 bytes in ... before you just filled up the cage. So, one of the other engineers did a board that had 4,000 bytes of static memory, but that wasn't enough for the programmers. So I did a board which had 16,000 bytes of memory, and I used DRAMs. These were some of the early DRAMs that Texas Instruments was making. And so there's the block of DRAMs, and here's all the control logic to interface to the S-100 bus, and this gave 16 kilobytes of dynamic memory. And that kept the programmers happy for a few weeks, and then they wanted more memory. So I did another board, and this one had 64 kilobytes of memory, right there. Full 64-K byte ... completely filled up the 8080 processor address space. You couldn't *put* any more memory in an Altair. Or *could* you? Because we put an I/O port on here with some switches, and you could choose, if you send a certain command to the I/O port, is this memory bank working or not; is it on or off? And the result of that was you could put eight of these boards in one computer, so you could now have half a megabyte of memory. And the programmers did that. They loved that, because it made the software run faster. So that was the biggest memory of that type that I made.

Now... remember the TV Dazzler used DMA to fetch the image out of the memory to display? Well, you think about it, once you start getting more pixels on the screen, closer together, you have to fetch more data. And pretty soon, you'll use up all the DMA bandwidth on the S-100 bus. There's no time left for the CPU. I actually made a board that worked that way, and the CPU got about 10-percent working time. The rest of the time, it was just doing display. And it was horrible to use that computer, because it was very, very slow. You'd type on the keyboard, and nothing happens, and then *chink chink chink*. You know? So... the next version of the TV Dazzler was called the SDI ... the Super Dazzler Interface. It's still on two

boards but did *not* use DMA to fetch the data from the computer memory. Instead, it had an extra connector on the top edge, that had its own address and data bus to go to the memory to fetch data. And the two boards were tied together with ribbon cables, now, on the top edge, so there's a lot of signals in those ribbon cables; and then a smaller cable on this board, that was sync ... I am not sure what that was.

So this is the DMA card. It has the D on it. And all of this stuff... we called it the DMA card, but it was really just fetching the data from this cable. This card generated all the timing for the display, and everything. And so then you flipped the stack over, and now here is the video card, which was underneath the DMA card. There's ... you can see the edge of the DMA card, but this is the video card, and it has a bunch of analog stuff over here, having to do with synchronization and video output ... some D-to-A circuitry, and so forth. So, some of the D-to-As were now being built on little custom resistor things. What are they called? Single inline packages, or SIP. And it had a custom-trimmed resistor network in it, so you could get an eight-bit D-to-A very cheaply. And so that's how we did that. So, this board set gave a resolution of 240 by 320 ... 320 horizontal, 240 vertical ... and 4 bits per color. Well, that's not even VGA, but it was better than the TV Dazzler, and it was in the S-100 bus, and this was before VGA existed, anyway. So, to feed that bus on the top of it ... here's that bus again ... I made a special memory board. These are all static memory chips. And data can be read or written from those memory chips from the S-100 bus, or it can be read out through the auxiliary bus to the display device. So this is a two-port memory. That's why it's called a 16-kilobyte TP, for "two port." And then, as we worked on building displays with more resolution, I made one that had 48 kilobytes, and in this case, it's dynamic memory chips. Still does the same thing: read or write S-100 bus, read out to the cable bus. And that worked well. And then we wanted more resolution, so I made another one that had 256 kilobytes, and it has all the dynamic memory. And it reads out, again, to the bus, to go to the display card.

And we made... oh, as an aside there, I wanted to get high-quality color images in for displaying, and the easiest way to do that was to use an ordinary analog television camera, feed it into this card, which would do all of the tricky circuitry to separate out the colors in the different parts of the image, and then digitize the data and send it to the computer so it could build an image on the screen. But it was a slow scan digitizer, not fast at all. It took it a couple of seconds to do an image. So then we finally made a full-television-resolution set of graphics cards. And so there's one kind of DMA card. This kind of DMA card only produced eight bits of data to go to the display. A different kind of DMA card produced 24 bits. Now I got 24 bits here and here and here, and it's all coming from a memory port. And then that was paired with a video card, and so now you can see the video stuff. This video stuff here is just what you have to use to produce the timing and synchronization of a broadcast studio, so that the color signals and the timing signals all exactly match what the broadcast studio is going to send out. It ... the studio sends you some reference things, and you have to copy them. And then the actual analog outputs were created by some D-to-A converters over here, are built with chips and resistor SIPs. And the video went out on a cable, here. And that was RGB video full-analog resolution, which is 756 pixels horizontally, 484 pixels vertically, and 24 bits of data per pixel at standard television rate. And then I made, finally, a circuit board which could take that video and put it through processing, and, as a result, take the RGB ... red/green/blue ... pixel video, and smush it all together with a subcarrier encoding, to produce an analog composite television waveform that was studio-quality. And this made beautiful photographs on studio monitors. And

this ... all of these last cards that I just showed you were the ones that were used to make that image of the Art Star graphics, was this last set of graphics cards, including the color modulator here.

Just to show you the nature of things, around the time that the TV Dazzler and some of the early boards, like the D+7A, were coming out, Cromemco put out a flyer ... color flyer ... with some of the boards in it. And so this is... I just wanted to show this. It's a little eight-page flyer. It has a ... it featured a picture on the front of something from the Game of Life being played on a TV Dazzler, and the inside of the first board, featured here, is called a Bytesaver. You put programmable, read-only memory chips in it, and you could store programs in it. So you didn't have to have a disk drive, or anything; you could just, from the front panel, literally type a program into that card, and it would work.

And one of the programs that you could get from Cromemco, that went in here, in the first slot, was a monitor program which allowed you to use an ordinary terminal to control the computer, instead of using the front-panel switches. And so Roger designed this thing, and it was very popular. And then the next thing in the catalog was the multichannel analog interface ... the D+7A. And there's that big, clunky connector, for connecting to the top connector. And then after that, the next two pages, the TV Dazzler got a two-page spread showing output from some of the types of programs you could run on it. And there's the card set. There it is on the screen of a color TV... which happened to be Roger's color TV that I modified for him, so it would accept composite video input, because you couldn't buy TVs with composite input in those days. And then the next pages, there was a CPU card; had a Z80 on it. This was a big deal, because it had extra processing capabilities, and it went twice as fast as the 8080 that came in the Altair. Roger did this one, again. And then there's the Altair Cyclops, which I did for the computer interface. And so you would use the Altair Cyclops, the controller boards, the TV Dazzler, and a TV set to look at things with a computer. And then the last of the catalog: a wire-wrapped board and an extender card, which I did so I could work on the prototypes for all those other boards. And so they put them in the catalog, also, because people wanted them, and then there's the joystick thing. I don't know who made that. They never told me. So that was the kind of literature that Cromemco was putting out in the very early days. So, you see, I did quite a few of the products that they were selling there, as being important products.

Spicer: So, it's October 3rd, 2017. We're here with Terry Walker, who has been telling us about his career at Cromemco. But, Terry, you also were pursuing a Ph.D. at Stanford at about the same time. Could you tell us what that was like, and then what you did after Cromemco?

Walker: Yes. Well, it was an interesting time for me, because I had about four years of industrial experience, and I got selected to come to Stanford to work on a new project, funded by the National Institutes of Health, to do ultrasonic-related things ... ultrasonic imaging, specifically ... with Professor Meindl. So I came in September of 1972, as a new person to California, having lived all of my previous life in Central Texas. <clears throat> So, of course I took courses and stuff, but as part of the arrangement for my coming to Stanford, I had a research position ... grant position ... part-time, and that

was enough to pay for rent for housing, and a little bit of money, otherwise. But it wasn't enough money for everything. So in some of my spare time when I was at Stanford, I was doing consulting on various jobs for lots of different companies around the area, designing circuit boards, for the most part, and so that kept food on the table. And the research that I was doing at Stanford was related to ultrasonic imaging. I used my experience with design to design the display electronics for some of the early ultrasonic probes, which they made. And then later, for my actual doctorate work, I designed and built an ultrasonic imaging machine, which used a phased array linear scan technique. The array had 32 elements in it, so I had 32 receiver channels in the machine. Each receiver channel had a charge-coupled device that was used as a variable time delay, and this whole assembly of 32 channels was controlled by a microprocessor ... an 8080. It was the first microprocessor project I had worked on. This was before the Altair computer, and all of that. And I had actually made a very elemental microprocessor with an 8080 and a ROM chip on a card, along with a little bit of other interface electronics. There was no RAM. The program was so simple that all the temporary storage was actually in the registers of the 8080. And furthermore, it all fit in a ROM chip, which was a 1702, which hardly held anything, but it held enough. And so I was able to put a program in that, that would scan the linear phased array. So that was my doctoral research project, and after that was done, ultrasound was growing up, you might say. A lot of different techniques were happening. Stanford was making a number of custom ICs for ultrasonic imaging usage, particularly high-voltage multiplexer chips that you could put between a transmitter and a receiver, and the array itself. And so when those became available and fairly well developed, I worked with other people to build an ultrasound machine that looked like a commercial machine. And it was used over in the Stanford Hospital, in places like the preemie baby area, to look at them. They could scan the head to see if there were things wrong inside the brain, and stuff like that. And it had a small television-type display on it, and it actually worked quite well. A external company eventually licensed that design and manufactured some machines, and sold them on the commercial market.

Spicer: Could I ask, how common was ultrasound as a diagnostic tool at this time? Was it still experimental, or was it ...?

Walker: At the time that I went to Stanford, there was no commercial ultrasound, except for single-transducer systems. Like, there was a system that had a single transducer, and you would stick it on the side of your head, and it would shoot an echo back and forth through the brain. And if you had a concussion, like football, the concussion would cause a hematoma inside the skull, the brain would shift in position, and you could see the center of the brain ... the midline ... moved. And that was the only real kind of ultrasound going on at that time. So, what we did with the NIH grant was, we developed various ideas for electronic scanning of ultrasound arrays, and published a number of papers and things. And the people out in the world, with the engineering companies, looked at this and said, "Hey, we can do this, too." And they put ten times as many engineers and money on it, and quickly sort of ran away with the whole ultrasound imaging area, developing it much faster than we could, so that by the time the grant ran out, five years later, there were already a number of ultrasound machines ... commercial machines ... on the market that were quite good, made, originally, based on research from Stanford and other places. There were other places working on it, also.

Spicer: Yeah. Amazing. And what ... did you work on other significant projects, or...?

Walker: Oh. After the ultrasound at Stanford ... I got my degree about the time that the ultrasound contract ran out, and so I took a position as a research associate at Stanford, working in the IC Lab. And what I did was, I just ran the testing area. We had several kinds of machines and specialized measurement equipment that people would use for their projects, to measure the properties of MOS transistors or diodes or bipolar transistors ... whatever they were making. Because there were a lot of people ... graduate students ... there, who were working on trying to develop new processes and new techniques for making integrated circuits. So I ran the testing area, up until '87. And, you see, the Cromemco stuff all took place between '75 and '87. That was the heyday of the S-100 computers, and stuff. And so in '87, I'd left Stanford, ran a small company with a friend for four years. And then, after that, I just became an independent consultant, working for a lot of different companies.

Spicer: So that's basically the second half of your career, has been as a consultant?

Walker: That's right. So, from 1991 until 2015, I just worked as a consultant. I did a lot of different kinds of things. I did some IC designs for a few companies. In the early years, most of it was small circuit boards for system applications; not things that you would sell to a consumer, directly, but that might be used industrially as *part* of something you would sell to an industrial consumer. For instance, one example was, there was a company called Amfit that made ... they had machines that you would now call robotic. They were just servo machines that would cut special insoles to go in your shoe, to match the shape of your foot. I did all the electronics for all the Amfit machines, over a period of 10 years or so. And then, eventually, I started doing more and more IC designs, and ended up spending most of my time working for one semiconductor company, here in the valley, and doing a lot of their advanced IC designs in that area. Now, when I was working there, I made use of my Stanford experience with ultrasound. And so I was making a number of different integrated circuits that were used specifically for ultrasonic imaging machines. And it's amazing. The ... some of the latest ones that we made there would be like a ultrasound transmitter chip. It would have 4 channels on it that would ... each channel is capable of putting out a 200-volt peak-to-peak square wave at 2 amps. So that's 400 watts of instantaneous power, 4 channels. So if you hit all the channels, you'd be putting out 800 watts from a little chip that is about, oh, 6 or 8 millimeters square. And, obviously, you can't do that continuously, because it's just going to go into meltdown. But in an ultrasound machine, the transmitter only operates like 0.1 percent of the time, so it cools off between pulses.

Spicer: What is the operating frequency of most ultrasound machines?

Walker: Well, the early stuff that we were working on at Stanford was mostly around a couple of MHz. And these days ... and the machine that we made that worked on premature infants was on... 10 MHz, I think. So it was pretty high. And most machines that you see in a diagnostic use, in an office these days, are somewhere between 2 and 10 MHz. The higher the frequency is, the less distance you can go into a

human body. So if you want to image organs that are deep in the human body, you have to use like 2 MHz. If you want to look at something near the surface of the body, like muscles or something, whatever you want to look at, you can use a higher frequency ... up to 10 megahertz ... because higher frequencies give you a picture with more detail, better resolution.

Spicer: Right. Right. Tell us a bit about Gravity Probe B, and what you worked on there.

Walker: Ah. That was one of the most fascinating consulting jobs that I had. The senior researcher in charge of Gravity Probe B was... uh-oh. I forgot his name. What was his name? Francis...

Janis Walker: Francis Everitt.

Walker: Everitt. Francis Everitt. So, Francis Everitt knew that I did electronics, because we had gone to the same church, from time to time. And so they had some problems on the project. And so he came to me, and I did a couple of consulting jobs for their satellite that actually was sent up to go around the Earth. One of the most interesting items was, Gravity Probe B worked by taking some quartz spheres that were about an inch and a half in diameter, and suspending them in a vacuum, using electrostatic forces from small metal plates. It turns out that if you're sitting on the earth, at one g of gravity, you have to use like 2,000 volts on the electrostatic plate to control the ball. And you want to control the position of the ball within a few micrometers, so you have very complicated servo systems. And they needed an amplifier that would generate that 2,000 volts, controllably. And I designed for them a little circuit board. It worked like an ordinary operational amplifier, like an ordinary IC, with a pair of inputs, but the output could go plus or minus 2,000 volts. And they used that for suspending the ball in the Gravity Probe B experimental equipment when it was being tested on the earth. And when they sent it up in the satellite, they just reduced the power-supply voltage to 10 volts. So it would only put out plus or minus 10 volts, and it suspended the ball when it's orbiting in space.

Spicer: Wow. Is there a way to explain for the layman what that proves?

Walker: Gravity Probe does?

Spicer: Yeah.

Walker: Gravity Probe B was supposed to test a theory of Einstein's about the interactions of the gravity generated by two spherical objects. One object is the earth ... it's a big, rotating sphere. The other object is ... on the satellite is this little quartz ball that is rotating fairly rapidly. It's superconducting, it's very cold ... liquid-helium temperatures ... and all of this exotic science. And, of course, the measurement precision is just incredible. It's like parts in 10-to-the-12, or something.

Spicer: Wow.

Walker: But if you have the Earth here, spinning one way, and you have your little ball here, spinning another way, think of it like two magnets. They generate some gravity fields that interact. And the result is, this little ball on the satellite will slowly change its spin axis, so it moves in a different direction. It rotates in a different axis. And so by measuring that spin axis when the satellite goes around the earth for a year, they could determine if Einstein's equations about gravity were correct or not. Now, the change in the spin axis ... I am not certain I can even state it correctly. One of the things they were measuring was 0.24 of one arc second, an arc second being a fraction of a degree ... a very small part ... and so forth. I'm not very conversant with all that science. But the bottom line was, the required precision was extremely good. And they managed to do it. And it said that Einstein was right.

Spicer: <laughs> That's good. And that experiment went on for decades, I believe, right?

Walker: Yes. Well, the actual satellite data collection was a couple years ... two or three years. The satellite ... I would say, 95 percent of the satellite was just a giant helium dewar holding the liquid helium, to cool all the electronics and the spheres that are spinning, because it had to be superconducting and various things. They had to get close to absolute zero to get rid of thermal vibration, and stuff.

Demonstration

Walker: I am now setting up a demonstration of the operation of the Cyclops and the Altair Cyclops cameras. We have both of them set up on the table here. Today is Tuesday, October 3rd, 2017. And this hardware is all stuff that I originally built. This is the original Cyclops camera ... first prototype ... which was built back in 1975. And then this is the Altair Cyclops camera, first prototype, which was built in the next year. And so, first off, the regular Altair Cyclops camera is set so that it is pointing at a target with the Cromemco logo on it, and it has an incandescent lamp illuminating the logo so that it can produce the best sensitivity. And so this camera is focused on that logo, as you can see, and producing the image on the oscilloscope. So this image contains 32 columns of 32 points per column of image points, whose intensity varies according to how much light is received from the target. Now, in this case, the target is just black and white ... pretty much constant, either black or white ... so there's not much grayscale seen in the photo here. And I'll show you something in just a moment, where you'll see more grayscale.

The Altair Cyclops camera is set to look at the same target, and instead of using an Altair computer with all seven boards, and trying to get it to run, which would be a crazy mission, I have ... I am using, instead, a small scan converter board, which I built for the Cromemco reunion a couple of years ago, and it simulates having an Altair computer, with the two camera interface boards, the two TV Dazzler boards, a CPU, a ROM card, and a RAM card. So that's all on that, programmed into a programmable logic chip. And so the signal from the Altair Cyclops camera, you can see here, is being imaged on this small

television, which is being used as a VGA monitor, using an external computer input. So now, to show you a little more grayscale, I will move this target, and instead put my hand out there. And so you can see the hand on the oscilloscope display. You can see how there's grayscale in the image. You can even see highlights off of the shiny ring. That's something I used to do with a digital watch. You'd get it on there, and you have a lot of highlights from ... if I can get it in the field of view, here. Where am I? There we go. You get highlights off of the chrome, and stuff like that. So you see various different brightness levels in the image; and also, you see the same type of thing in the image from the Altair Cyclops camera, which is over here. So here's the hand. And... up a little higher. There we go. So it looks pretty good.

Now, I am using, on the Altair Cyclops camera display, a software interpolation, so that I am producing a 64-by-64 image; but the image only contains the same data that would normally be in from the 32-by-32 imaging device in the camera. And I can turn off that interpolation. You'll see the difference. Now you see the image becomes much more blocky. It actually contains the same data as before. And the other interesting phenomena is that, often, when you're moving, you can see, on either display, the eye tends to interpolate the moving image so that it looks better. One last thing I want to show is... remember I mentioned in the lecture about the letter E making a pretty good target? If you line it up right, you can get it so that it looks pretty good on the display ... both displays. We can see the oscilloscope display on one side, and the Altair Cyclops display on the other. But if you look at letters which contain diagonals, like the letter V or the letter R, that there is a strange phenomena going on here, and that phenomena is because of the fact that the pixels, which are the DRAM cells in the image sensor, are actually not uniformly spaced. They were intentionally made with a mirror-imaging type of thing going on, and the reason for that was to make it possible to pack the circuitry more finely. For some reason, it doesn't look as bad on the oscilloscope display as it does on the VGA, but I think that's in part because, on the oscilloscope display ... yeah, see, it's dying ... there is a fuzziness to the spots. So that's pretty much everything that I wanted to show on the demo. Ah, one more comment: This is the original ... if you bought one of these Cyclops camera kits, you paid your \$60, you got a circuit board and some instructions, some small parts in a envelope, all of the ICs in a tube, like that, and an image sensor. So here's a type-B image sensor. This was a kit that I was given from the production, right after they started shipping them to various customers. So that's what I have to show today for a demonstration of the Cyclops and the Altair Cyclops cameras.

END OF THE INTERVIEW