George Caryotakis by David Zierler
Virtual Interview 27 May 2020

DAVID ZIERLER: This is David Zierler, oral historian for the American Institute of Physics. It is May 27th, 2020. It's my great pleasure to be here with George Caryotakis. George, thank you so much for being with me today.

GEORGE CARYOTAKIS: Very well, sir.

ZIERLER: OK. So, to start, please tell me your most recent title at SLAC.

CARYOTAKIS: Head of the Klystron/Microwave Department.

ZIERLER: You were the department head. Very good. OK. So, now, let's take this right back to the very beginning. George, tell me about your family background and your childhood.

CARYOTAKIS: Really?

ZIERLER: Yeah.

CARYOTAKIS: [laugh] All right. Well, I was born in Athens, Greece.

ZIERLER: What year were you born?

CARYOTAKIS: 1929.

ZIERLER: Were your parents Greek? Was your family all from Greece?

CARYOTAKIS: Yes, yes. But I left Greece— I left Greece and came to the States.

ZIERLER: How old were you when you came to the States?

CARYOTAKIS: Just turned 19. It was 1948.

ZIERLER: OK. Now, before we get to your move to the States, tell me a little bit about your parents. What did your father do for a living?

CARYOTAKIS: What he did was to work for one of the large banks in Greece. The National Bank of Greece. He was head of the unit. He worked there his entire life.

ZIERLER: And was this in Athens?

CARYOTAKIS: Yes, in Athens. We lived in a suburb called Filothei, where many of the Banks employees lived.

ZIERLER: Yeah. Did your mother work outside the house?

CARYOTAKIS: No, She didn't work.

ZIERLER: And so, tell me about your education in Greece. Did you go to public school?

CARYOTAKIS: No. I went to a private school called Athens College, from the American equivalent of Junior High school through high school. But during the war and German occupation I was schooled at home by teachers that my parents brought in. I learned French, and started mathematics. I learned English mostly at Athens College.

ZIERLER: Now, when you were 19, what caused you to come to the United States? Did you go by yourself or did your whole family go?

CARYOTAKIS: No, no. I came by myself and I had a scholarship.

ZIERLER: Oh. To what? What scholarship?

CARYOTAKIS: A scholarship to attend an American University, along with 2 other Athens College students. Athens College worked in conjunction with American schools. The faculty was a mix of Greek, British, and American instructors.

ZIERLER: You came by boat?

CARYOTAKIS: Yes. With two other scholarship winners. We landed in New York.

ZIERLER: Yeah. What school did you attend?

CARYOTAKIS: Syracuse University.

ZIERLER: OK. And did you study physics there?

CARYOTAKIS: I studied, yes, essentially physics.

ZIERLER: Now, did you know you were already good at physics in Greece? Was this something that you were strong at in school?

CARYOTAKIS: Not as much physics as engineering.

ZIERLER: And so, what was your major at Syracuse? Did you graduate with a major in engineering or a major in physics?

CARYOTAKIS: In engineering.

ZIERLER: In engineering. OK. And then, what did you do after Syracuse? Did you go on to graduate school or did you enter the workforce?

CARYOTAKIS: At Syracuse I was the valedictorian, the first time a foreign student had been. My physics professor Dr. Ottway Pardee, recommended me to Stanford on a Tau Beta Pi scholarship.

CARYOTAKIS: I went straight to Stanford with the Tau Beta Pi scholarship.

ZIERLER: I see. OK. And was this a scholarship in the engineering program? You stayed on as an engineer?

CARYOTAKIS: Yes.

ZIERLER: OK. What year did you arrive at Stanford, do you remember, as a graduate student?

CARYOTAKIS: It was 1951

ZIERLER: OK. And were you there to get a master's degree or a PhD?

CARYOTAKIS: Both.

ZIERLER: Okay.

CARYOTAKIS: One after the other.

ZIERLER: Right. What was your course of study? What was your PhD on?

CARYOTAKIS: In electrical engineering.

ZIERLER: OK. And what was it on? What did you study for your dissertation?

CARYOTAKIS: The title of my dissertation was *Iterative Methods in Amplifier Interstage Synthesis*. The work was done at the Stanford University Electronics Research Laboratory and the published work was submitted to the Naval Research Laboratory. All these things were paid for by the US government, and I was not a citizen yet, so I was unable to work on classified programs. But I was able to work in the Electronics Research Laboratory at Stanford.

ZIERLER: OK. And do you remember who your advisor was for your thesis?

CARYOTAKIS: It was Marvin Chodorow.

ZIERLER: OK. Very good. And then, after you defended your thesis, what was your next opportunity? Where did you go on from there? Did you go straight to SLAC or did you go somewhere else—well, before SLAC existed—I'm curious?

CARYOTAKIS: I joined Varian Associates in 1956. I wrote a letter to Ottway Pardee thanking him for guiding me to Stanford and announcing how pleased I was to be joining a group "of highly trained and widely recognized physicists and engineers working in microwave, and applied physics fields. " My thesis advisor, Marvin Chodorow and Stanford Professor Ed Ginzton, were acting as engineering consultants at Varian. Varian was working on the things that I found interesting, Klystrons and Traveling Wave Tubes, Magnetrons, High frequency triodes, cutting edge technology at the time. The thrust at Varian was Klystrons, with TWT's just beginning. They built coupled-cavity tubes and the first commercial cloverleaf tubes, with Chodorow as a consultant. These were megawatt tubes. By 1959 Varian had begun to make integral cavity tubes to replace the external- cavity tubes which had problems. So Varian built the largest integral cavity tube that existed at the time. I got involved, helping to make that tube broadband. I had been at Varian about 4 years and although I enjoyed the work, I was not happy

with the management and I didn't like my boss. One day, I received a call from a competitor, Eimac. In 1960 Eimac hired me to put them in the integral cavity klystron business, which was taking off, going to higher frequencies. They had tried in Tropo to move from UHF to S-band. Eimac apparently had spent a fortune but the tube wouldn't work. They hired me after seeing a paper I had published, and put me in charge of a lab in Belmont, CA managing all the PhD's that they had hired. I was put in charge and my job was to develop a 10-kilowatt S-band tube and a 10-kilowatt X-band tube similar to what Lou Zitelli had built, at Varian which was state of the art. This was one of the best times in my career. It was a good group of people. We had a purpose, which was to beat Varian. We landed a contract with the Air Force for a megawatt CW X-Band tube. This was quite a coup, considering who we were competing with. Lou Zitelli had stated that it couldn't be done, so imagine our motivation! It was in two phases. The first one was to put the beam through the structure and show that it could be done. We figured we would run at 30 percent efficiency or so, and needed a 3-megawatt beam out of the gun into the tube collector. So we needed a collector about the size of a big garbage can. We won that phase. We had to have 99.9 percent transmission. We built a beam tester and the damned thing worked. We built a huge power supply, so large that we could only run it at night because the factory needed the power during the day. We made it work. Then we put in, probably the first, high-power extended-interaction output cavity. It was a two or three section, maybe four disk loaded structure. It was there expressly to increase the surface area to overcome circuit losses, and we had half a megawatt CW. Shortly thereafter we were producing very high-power CW kylstrons achieving an amazing 1 Megawatt CW at X-band. At this time, 1965, Varian acquired Eimac, so I was back working for Varian, where Tom Sege put me in charge of the combined Traveling Wave Tube division, where we got involved with Electronic Counter Measures helix tubes, as

well as tubes for communications. Sege decided to combine klystrons and TWT's and he put me in charge of that division, called the Palo Alto microwave and tube division. We initiated work on the Inductive Output Tube (IOT), called the klystrode at Varian. I ran that division for a number of years.

ZIERLER: As your responsibilities were growing, I'm curious if you every took formal training in management.

CARYOTAKIS: In 1977, I asked Tom Sege for approval to attend the Harvard Advanced Management program for three months, he agreed. I left Larry Moore in charge, and headed to Harvard. Just before I left, we took a contract from Raytheon for SLQ 32 mini tubes, nine thousand, priced on a "learning curve". Tom was having fits with Moore saying that he was wrapping $5000.00 around every tube. Tom was a micromanager and the net result was that Moore left Varian. Ultimately the costs did come down and the program was a major success.

In 1981 I was promoted to Electron Device Group President. After four years of enduring Tom's micromanagement and unrealistic budgets, I recommended Norm Pond to succeed me as group president, and I went to Zug, Switzerland to run Varian European Operations.

ZIERLER: OK. After your work here at this job, what did you do next?

CARYOTAKIS: All right. So, after Varian, around 1988, an old classmate from Athens College contacted me to see if I'd consider being his CFO. Dr. George Hatsopoulos had built Thermo Electron into a $3 billion company that was growing rapidly and he needed help. We had known each other since childhood; he was two years older than me, but our interest in science and electronics had been sparked early by the same event. You see, during the war the

Nazis had occupied many of the homes in Filothei, taking over the upstairs and forcing the families to live in the basement or out completely. Both of our houses were occupied but we were secretly building radios for the Greek Resistance fighters, in the basement. Hatsopoulos had come to the US on scholarship two years before me and earned his BS, MS, and PhD at MIT, after his PhD, he started Thermo Electron in Cambridge Mass. So, Lisa and I moved to Boston and I became a CFO. It became obvious rather quickly, that my personality was not well suited for selling guidance to stock analysts, or lobbying FASB on advantageous accounting regulations. I didn't care for the job and we parted a year later on friendly terms. Back in California, considering retiring for good, friends called, asking if I had seen the ad in the *Stanford Daily* for a person to head the Klystron department at SLAC.

ZIERLER: George, let's talk about when you joined SLAC. What year was that and how did that come together?

CARYOTAKIS: I was hired to replace Matt Allen, who wanted to retire.

ZIERLER: Do you remember who hired you at SLAC?

CARYOTAKIS: It was January 1990. I was hired by Greg Loew, and Burt Richter who was the SLAC director. I was told that Greg felt hiring me, a high power klystron manager, was an opportunity that SLAC could not and should not pass up. However, Burt Richter had reservations, regarding my management style, since my career had been in industry. After conferring with me that SLAC had a "University culture" I assured both men that I would happily leave profit drive at the door, and I welcomed a collaborative, knowledge driven management style.

ZIERLER: George, what did you do at SLAC, what was your job?

My department was to maintain/repair the klystrons that were currently powering the SLC Accelerator. And to design, develop, and manufacture the klystrons required for new and future programs and importantly, to be a backup for industry. The SLAC Klystron/Microwave department was dedicated to the design and production of increasingly more powerful microwave sources and had developed specialized techniques to achieve this purpose. When I came on board, the klystron department had the responsibility to manufacture and rebuild all of the 5045's klystrons that were powering the accelerator. All parts had been custom designed and manufactured in house or at top notch machine shops for micro-finish applications. Cathodes were also purchased and custom.

During my tenure, two major programs were launched or under way, the Next Linear Collider (NLC) and the B Factory. I held weekly Monday meetings with all the players to review the programs and discuss issues. I needed to understand completely what the physicists wanted in order to produce the appropriate microwave power sources. My area would then design, simulate and build. I was essentially the go-between for the physicists and engineers. My department was represented by engineers and manufacturing (Chris Pearson), Ron Kuntz and Saul Gold. Also present were Ewan Patterson, SLAC technical Director, Greg Loew, Ron Ruth, Head of Accelerator Research and the NLCTA, Dave Burke, Program Director for the NLC and Chris Adolphsen also for the NLC. It was an open meeting and different people from manufacturing or engineering also attended many meetings in the background.

The NLC design was for a 1-TeV collider. The choice of X-band as the operating frequency, along with the sheer size of the NLC required klystrons well beyond the state-of-the-art at the

time for microwave tubes in the US or abroad. The specifications were approximately Frequency 11.4 GHz; peak power 75MW; Pulse Length 1.5/spl/mu/s; Repetition Rate 180Hz; Gain 50dB; Efficiency(including beam focusing) 50%. The goal for power output was 100MW X-band klystron which would break new ground. An existing tube that only approached this performance was the workhorse of the Stanford Linear Collider (SLC), the 5045 klystron with an output of 65MW at 3.5/ms and an average power of 40KW.

Several stages of research and development were necessary to reach the klystron level required for the NLC and B Factory. The SLAC-5045 was the departure point. In order to lower R&D costs, I worked with the engineers on developing simulations for the klystrons. I had engineers using both simple models (Japan disc) to initiate parameters for the more sophisticated models like MAGIC and another program. We made the software easier to use by developing front ends to load data, etc. Aaron Jensen rewrote Japandisk in C++. I hired a person to do only simulations to help the designers.

The first X-band series of klystrons was dubbed the XC1-thru XC8. (Simulated with CONDOR code) There was an urgent need for high-power sources to test accelerator components at 11.4 GHz, and it was felt that much could be learned about the design of output circuits even if the perveance was high and the efficiency on the low side. There were many window failures, both in the tubes and experimental setups, which led to the decision to abandon the TE_{11}- type windows, which required current to flow across the metalized and brazed joint between ceramic and metal, and to employ TE_{01} windows instead, particularly since in the proposed NLC all power transmission between the klystrons and the accelerator was by means of circular TE_{01} waveguide to minimize transmission losses.

I remember that Bob Philips, who I had hired, and had known from industry, designed a low cost ring loop TWT as a driver for the NLC klystron. He worked with industry to have the tube built.

Bob Philips and I thought that it would be better to back down the peak power of the XC and that led to the next series of klystrons the XL series, which were to be the sources in the Next Linear Collider Test Accelerator (NLCTA) and operated at 50MW, at 440kV and 350A. The XL's were all built with single TE_{01} windows.

During the build of the XL's, development of the 100-MW klystrons was to continue using the 600-kV modulator for test. XC and XL klystrons used a large amount of magnet power to focus the beam. Given the number of klystrons needed to power the NLC , the power budget did not permit the use of electromagnets. This "problem" led to the idea for a Periodic Permanent Magnet (PPM) focused klystron.

By 1996 my department had designed and built a successful X-band 50MW PPM klystron. It was like the XL but PPM focused for use in the NLC. Daryl Sprehn designed it. The major advantage of PPM focusing was in the cost savings of DC power. Potentially tens of millions of dollars per year when powering the NLC as envisioned. In order to achieve the NLC baseline of 1 TeV energy level, would require thousands of 50MW and 75MW klystrons, so cost of energy consumption was a practicality that needed consideration.

What followed the success of the SLAC designed 50 MW PPM klystron in 1996 was the build of the 75 MW X-band PPM klystrons constructed by SLAC, KEK, and industry. By 2004 two were built and one of these was successfully tested to the full NLC specifications of 75MW, 1.6microseconds pulse length, and 120 Hz. This 14.4kW average power operation came with a tube efficiency >50%.

Subsequent to this successful test, a study was done at SLAC that higher frequency could deal with higher gradient and so the idea for a W-band accelerator was born. My department then led development of a W-band klystron. The basic development showed Accelerator, Military, Civilian and Medical applications. I worked to get outside funding to pursue this research, but the physicists resisted, wanting the department to be at the ready for their needs.

I also attempted to have the klystron Department named a Center of Excellence for SLAC, in order to preserve design and development technology that was no longer being done in industry. Again this was resisted. The political and budgetary winds were not with us.

ZIERLER: And what was your job specifically on the B-factory?

Caryotakis: To develop a power source that would create the necessary power for the Positron-Electron Project II (PEP-II), an asymmetric collider, to produce copious quantities of B mesons-sub-atomic particles containing a bottom quark. The physicists' goal was to measure the lifetime of a B meson and a B-bar meson. My job was to produce the energy for the two beam collision that would present these particles.

The B Factory klystron (BFK) project was a joint undertaking between SLAC and Varian. The BFK was 15-ft. long and operates horizontally. It operates at 90kV, with a microperveance of 1 and produces 1.25-MW CW. It has 7 cavities which are tuned capacitively by moving a flexible cavity wall and changing the gap length. Overall efficiency is 60%, gain 50dB and the nominal band with is 10MHz. The collector is capable of dissipating full beam power.

ZIERLER: Now, George, you said this was your second-to-last project at SLAC. What was your last project?

CARYOTAKIS: Not a project really, but I wanted to record a history, of the High-Power Klystron work done at Stanford University and at the Stanford Linear Acceleration Center. I authored a history in a two part SLAC Publication titled: *High Power Klystrons: Theory and Practice at the Stanford Linear Accelerator Center.*

ZIERLER: When did you retire from SLAC?

CARYOTAKIS: In 2006.

ZIERLER: Looking back, George, in what ways did you contribute to the mission at SLAC?

CARYOTAKIS: Well, you know, I provided the physicists with the tools they needed to do their research. I worked with some good people. I worked with some difficult people. [laugh]I worked with professors at Stanford that were well trained. And, in general, I enjoyed myself. I think that's a reasonable statement.

ZIERLER: What did you do after your retirement at SLAC?

CARYOTAKIS: I went back into industry for a couple of years. I joined Communications Power Industries (CPI) which was a spin-off from Varian when the last CEO, Tracy O'Rourke, broke up the company and sold various divisions in Levered Buy-Outs. CPI was housed in my old Varian offices on Hansen Way in Palo Alto.

ZIERLER: Well, George, it's been so nice speaking with you today. Thank you so much for spending the time with me.