Terahertz Pioneer: Shenggang Liu

"China's Father of Vacuum and Microwave Electronics"

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PROFESSOR and President Shenggang Liu[1] came into the world as the last of 11 children on December 26th, 1933 in Feidong, a part of Hefei city, approximately 100 km west of Nanjing. Since December 26th was already an auspicious birthdate claimed by the late Mao Zedong, an alternate birthday was considered to be politically more acceptable. December 25th was also taken by a well known historical figure—and who wants to celebrate a birthday on Christmas anyway—so December 21st became Shenggang Liu's birthdate of record.

Shenggang's mother was 43 when he was born and she was unable to nurse him. Instead he was fed a local formula derived from rice—perhaps that was just the nutritious diet he needed to form the neural interconnects that would later make him such a gifted physicist!

Professor Liu's father, Liqiao Liu, was a middle school teacher of history and culture. Shenggang credits his mother for his intellectual gifts. However, perhaps it was actually his father's steadfast clinging to a career of teaching, in the midst of tremendous obstacles, that instilled in young Shenggang, a desire to eventually become an academician.

Shenggang was one week shy of his 4th birthday when the invasion of Nanjing turned his family's life into a continuous seven-year long nightmare. The family fled first to Zhijiang in Hunan province, and then to Guiyang in Guizhou province, and finally to Chong Qing, the temporary capital of war-ravaged China, and located in Sichuan province. The family made much of the journey perched precariously on the roofs of transport trucks. Nothing during this period can be described as anything but one horror after the next. Perhaps the only bright spot, from my own point of view, was the admiration that Shenggang developed for the airmen and support teams of the American *Flying Tigers*, who had a base in Zhijiang for launching air strikes against the invading troops. These early memories of the Americans and their aid to the refugees (Shenggang used the terms "with their blood and their lives"), were held very dearly in his child's heart and were to help shape a lifelong affinity with the U.S., and with western science and culture.

SHEGGANG LIU

At age 11, Shenggang was able to take the test for entering middle school, and despite having dropped out of primary school to care for his mother during the war, he passed the exam easily, and left home to move into the dormitories of the middle school in Qingmuguan near Congqing (this middle school was affiliated with the National Central University). There he received free food and lodging. Shenggang, *and all his 10 siblings*, were able to take advantage of this life saving wartime relief offered by the Chinese government to young students, thus releasing his mostly-out-of-work father from the burden of his childrens' financial care. Shortly before the war ended, Shenggang's father, with great effort, was able to secure a meager job in the Ministry of Education. This opened up an opportunity for Shenggang and his family to return to Nanjing (he and his father) using transportation supplied by the Ministry of Education (free of charge). Shenggang was able to continue his studies in the same middle school, which was also moved to Nanjing from Qingmuguan, at this time. His mother went back to Hefei city. One year later, Shenggang's father left the Ministry of Education and went back to Hefei to join his wife, where he found a job as a teacher in an elementary school.

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[1]This interview was conducted in a far-off place with an extraordinary individual who has lived and worked consistently and passionately as a career scientist in a country that has been through nearly incomprehensible political and economic changes over the past six decades. I met Professor **Shenggang Liu** in his Spartan office in what was the old vacuum tube assembly factory on the campus of the University of Electronic Science and Technology of China (UESTC) in Chengdu city, located in Southwestern China, on October 31st, 2013. It happened to be on the occasion of his university's celebration of his 80th birthday and of his 18 years as Vice-President and then President of UESTC. I sat transfixed for almost 8 hours as I heard one of the most amazing stories of career passion and personal triumph over adversity, as I have ever encountered. With the help of a science translator, a graduate student, and an eldest son of Professor Liu, I have compiled the personal story that constitutes the bulk of this article. I have interspersed this story with some of the more significant technical achievements that have come from Professor Liu's 60 years of scientific study. Since much of China was closed to western scrutiny from the 1950's until the 1980's, many of the scientific and technical achievements that Professor Liu is responsible for have not been published, or made available, outside of China. However, when the first of these finally did emerge at the *4th International Conference on Infrared and Millimeter Waves and their Applications* in Miami, FL, USA in December 1979, they immediately impressed the western scientists that were in the audience, and launched Shenggang Liu on an internationally recognized career path that was to continue to the present day. I am certain you will enjoy his story as much as I did.

Shenggang remained in Nanjing, graduating in 1948, and went on to Hefei to continue his studies. After finishing high school, he went to Hangzhou city to study in Zhejiang University, one of China's best higher educational institutions.

Shenggang was interested in physics, but he was told that the job prospects in engineering were a lot brighter, so he selected electrical and electronic engineering as his undergraduate field of study. The entrance exams in electrical engineering were harder than the ones in physics at this time, but Shenggang passed them handily. *(For those of you who might still harbor deeply rooted convictions about which of these fields is the most demanding, take note! voc.ed.)*.

Shenggang soon completed his general engineering training, and in 1953 he began specialized studies in physics, and eventually in vacuum electronics, which would become a lifelong focus for him. He moved to, and graduated from Nanjing Polytechnic Institute (renamed Southeast University in 1988) in 1955 as one of only 5 students to complete an undergraduate thesis. This was on the design of a process and the accompanying machinery to mass produce vacuum tubes. It contained detailed calculations of the flow rate and time it would take to make and seal off each device. The thesis was completed in record time, a few months, much to the shock and admiration of his advisors. Shenggang was thus considered an outstanding student, and was allowed to stay on at the university after graduating to help out the permanent faculty.

At this time there was a major collaborative program to bring Russian academicians into China to help set up and train scientists in areas that were not well represented. One of these was microwave electronics. Professor Igor Vsevolodovich Lebedev [1], a prominent Moscow physicist and author of several books on microwaves [2], [3], was to arrive the following year to set up a special institute in Chengdu that was to draw together faculties from three universities: Nanjing, Shanghai and Guangzhou, under the Chengdu Institute of Radio Engineering (CIRE). Shenggang was told that he was to be Lebedev's translator!

Shenggang knew little about microwaves, and even less Russian! His Nanjing professors knew he was a fast learner however, and Shenggang did not let them down. In five months he taught himself the principles of microwave physics and a reasonable amount of Russian, to couple with his bits of high school English and German. He was sent off to meet Lebedev on his arrival in Beijing in August 1956. Unfortunately, there were no cell phones, internet, or texting back then, and it took Shenggang 3 full days to find Lebedev in Beijing (even this is miraculous given the size of that city). When he finally did make contact, plans for the move to Chengdu were in serious jeopardy. Several organizations, including the Chinese Academy of Sciences, Tsinghua University, Nanjing Politico College, and others, wanted to have Lebedev working in their own institutions. After a month of haggling, the Ministry of Education made a decision that that Lebedev would go to Chengdu. That year, Shenggang together with Professor Lebedev, made the 1800 km journey from Beijing to Chengdu.

Shenggang arrived in Chengdu in 1956, but he stayed for 57 years. His one regret was the loss, during the shuffle of his move from Nanjing, of a favorite and fairly expensive bookcase that he had bought with his first month's salary working for the new Institute!

In Chengdu, Shenggang worked with Lebedev as a translator. At that time, a number of young teachers and graduate students from more than 10 universities and research institutes in China came to Chengdu to learn about Microwaves. Liu prepared all the course notes for the students at CIRE, helped with problem sets, and made up and supervised laboratory exercises. He also translated and contributed to 3 widely used Chinese textbooks on microwave theory and techniques. Lebedev was so impressed, both with Shenggang's Russian and his knowledge of physics, that he asked the Secretary of the Party to admit Liu as a graduate student. Lebedev went even further, and had the Party Secretary implement a graduate degree system at CIRE equivalent to the one used in Russian universities. In 1958, *Dr.* Shenggang Liu became the first and only student to graduate with a Ph.D. under this new degree program. Unfortunately, Lebedev returned to Russia in 1958, and the degree program was terminated immediately afterwards, with poor consequences for the Party Secretary! It took many years before Shenggang Liu was again able to officially declare himself a *Doctor of Philosophy*.

When Lebedev left Chengdu, Shenggang served as an assistant to the faculty. His first major paper came out in 1959—on focusing of electron beams in coaxial systems with and without space charge effects [4]—and he was quickly promoted to Lecturer. After 1964, he was an Associate Professor and his now well known research on the analysis of electron trajectories in curvilinear coordinate systems (extremely applicable to coaxial cavity electron-cyclotron maser design—*gyrotrons*) was taking shape [5]–[7]. He also worked on microwave tube theory, design and analysis, and he taught courses on microwave technology and vacuum electronics.

By 1966 however, things were starting to go terribly bad. The Cultural Revolution was in full effect and Professor Liu was forced to stop teaching, and instead to mop floors and clean toilets. His house was searched and all his valuables confiscated. He was repeatedly rebuked, and forced to march around the university grounds as an act of shame, while being publicly ridiculed. Eventually, he was sent off to the mountains to herd cows. Fortunately, he brought his text books with him and could often be found pouring over physics problems amidst the barnyards.

No one reported smarter cows, but Shenggang Liu returned to Chengdu a smarter man. The zealous re-education campaign finally came to an end in 1976, and "*Professor*" Liu once more, Shenggang was able to resume his teaching duties. During the ten year teaching hiatus at the university, Liu had secretly been using the microwave laboratories with some of his former students to work on backward wave tubes and slow wave serpentine structures. Immediately after his reinstatement he was able to publish a very complete paper on their mode design and analysis which appeared in *Science China* in 1977 [8].

At the same time as he was beginning work on microwave tube structures, Liu was approached by government science officials, who were keenly aware of the importance of the microwave field, and who realized the shortage of available knowledge in China on this subject area. Liu was asked to spear-

[2]Early textbook translations (from Russian) with contributions: *Microwave Theory and Technology, Microwave Vacuum Devices*, and *Microwave Measurements*, 1956–1957.

head an effort to produce a series of Microwave handbooks for the Chinese science market. This multi-volume series, *Handbook of Microwave Design*, took Professor Liu almost 4 years to complete. He was the working editor, and contributed two of the volumes on tube design [9], [10]. The series covered every aspect of practical and theoretical principles in the field. In 1980, shortly after the book series was finished, Liu became one of the youngest elected academician members of the Chinese Academy of Sciences.

Liu now focused his, and his department's experimental and theoretical work, mainly on gyrotrons (electron–cyclotron–resonators—ECR) and electron beam structures. He set up the *Research Institute in High Energy Electronics* at the university to pursue these interests with his students and staff. He had read Granatstein's classic paper on electron-beam amplifiers [11], and felt that Chengdu's vacuum electronics laboratories could better contribute to this niche but growing field, rather than attempting to follow the lead of many solid-state physics departments which were pursuing semiconductor devices. His first major contribution to the field came in 1979 with a highly regarded theoretical paper in Chinese Science (*Scientia Sinica*) on gyrotron mode matching and focusing in cylindrical and coaxial geometries [12].

Liu made his first trip to the United States in December 1979 to attend the *4th International Conference on Infrared and Millimeter Waves and Their Applications* in Miami, Florida, where he presented a paper on electron cyclotron resonance theory [13]. There he met well known Chinese physicist Ren Zhigong (Chih-Kung Jen), then at Johns Hopkins Applied Physics Lab, who had a strong affinity for young scientists from his home country [14]. Ren was so impressed, he presented Liu with flowers after his talk. Liu also met noted tube experts Jay Hirshfield (now at Yale University) and Kwo Ray Chu from Naval Research laboratory (now a Professor at National Tsing Hua University, Taiwan). After this, Liu rarely missed another event in this long running series of conferences which has just had its 38th meeting this past September in Mainz, Germany [15]. The next year, in Wurzburg, Germany in 1980, Liu returned to the conference and presented a paper [16] that expanded upon his 1979 maser analysis by including space charge effects (the cloud of electrons that forms around a hot vacuum cathode and has an impact on the accelerating electron beam). A more complete journal paper was published shortly afterwards [17].

By 1981, Liu had further refined his ECR theory and began constructing experimental gyrotrons in his lab at Chengdu [18]–[20]. He realized that there were significant hurdles in the construction of the oscillators and amplifiers that had to be overcome in order to reach higher frequencies. One problem was the confining waveguide cavity and the other was the very high magnetic field that would be required to contain the fundamental ECR harmonic. In 1983, he proposed a quasi-optical cavity design to overcome the waveguide confinement, and the use of higher harmonic modes to reach into the millimeter-wave bands without employing excessively large B-fields [21], [22]. Liu expanded these concepts into a novel 3 mirror open cavity system [23]–[26] and to an all electrostatically focused maser design that employed no magnetic field [27]–[30].

The electrostatically focused maser concept was also applied to Free Electron Lasers, which generally employed a wiggler (undulating magnetic field structure) to generate the electron oscillations that give rise to the Compton (two-wave) or Raman (three-wave) scattering instabilities that produce the output power. Liu proposed a "wiggler-free" structure using a coaxial geometry with two axially injected and opposing electron streams that interact to produce the scattered wave output [31], [32].

By this time, Liu had integrated himself into a large network of international colleagues focused on high power electron beam sources for the development of the plasma fusion field. He brought many of these individuals together in China for the first time when he helped organize, with V. I. Granatstein and M. E. Read, the *4th International Symposium on Gyrotrons and Free Electron Lasers* held in Chengdu in June 1987 [33]. He also brought many colleagues to China, individually, before there were normalized relationships with their home countries. Liu's technical work continued to focus on both high powered masers and Free Electron Lasers and a few of his more cited publications from this period can be found in [34]–[41].

Given his international stature, it was not too surprising when in 1983, CIRE officials approached Liu and asked him to take on the job of University Vice-President. He accepted only under the condition that he could continue to pursue his research and work with his students. True to his pledge, he focused on his research even as he helped with the daily activities of running the school. During his term as vice-President he wrote two textbooks that were very widely read, one on Introduction to Microwaves in 1985 [42] and another on Relativistic Electronics, released in 1987 [43].

In 1986 he stepped in as University President, again under the condition that he could keep his research going. He made sure this would happen by drawing his salary not from the university management account, but rather from the *Research Institute in High Energy Electronics* that he had set up eight years before. As UESTC President he did four things he is exceptionally proud of:

He changed the name of the university from the original Chengdu Institute of Radio Engineering (CIRE), to the University of Electronic Science and Technology of China (UESTC), dramatically broadening the scope of the institution.

He helped get UESTC into the "211 project" making it recognized as one of the top 100 universities in China, and then into the "985 project" bringing it into the top 30.

He made UESTC the first university in China to confer a Ph.D. degree in a "cap and gown" ceremony, even though he had to have tailors custom make the caps and gowns from pictures he found himself in the *Encyclopedia Britannica*. He also did this at the peril of government policy makers, but his example was so well received by other universities, that the practice is now widespread in China.

Finally, he is very proud of the international outreach that he has championed, which has resulted in many exchange programs and exchange visits to and from university officials in UK, Canada, US and Japan. These have greatly enhanced UESTC's international reputation.

During the latter part of the 1990's, Liu continued to work on electron beam interactions [44], [45], expanding into propagation effects in various waveguide structures [46], [47], and working on particle in a cell (PIC) numeric analysis

tools [48]. He traveled to Old Dominion University, Norfolk, Virginia in 1997, where he hooked up with Electrical and Bioelectrics Engineering Professor, Karl Schoenbach, and Air Force Office of Scientific Research program director, Robert J. Barker, to work on biological effects and medical treatments of high field electromagnetic energy. This collaboration resulted in the *First International Symposium on Nonthermal Medical/Biological Treatments Using Electromagnetic Fields and Ionized Gases (ElectroMed99)* as well as a full special issue of IEEE TRANSACTIONS ON PLASMA SCIENCE on this subject in 2000 [49].

In 2001, President Liu stepped down from his post and went back to his research and teaching functions. He had been very interested in high frequency devices since he had successfully designed and fabricated gyrotrons working close to 100 GHz back in the early 1980's [28]. A recent trip to Nara, Japan and the *7th International Conference on Terahertz Electronics*[3] in 1999, had convinced Professor Liu to focus his remaining years on the pursuit of THz science and technology. He founded an Institute with this name—*Terahertz Science and Technology Research Center*—at UESTC in 2001, and he has since devoted much of his time to promoting this expanding field in China and around the world.

Professor Liu is particularly interested in THz *applications*, and in 2005, he started a bi-annual conference series in Shenzhen, China: SICAST—*Shenzhen International Conference on Advanced Science and Technology*. This conference series caught the attention of government funding agencies and has since helped stimulate more than 60 university programs on THz research in China. The 2013 conference was held in Shenzhen this past November 4–6th. Liu also started an all electronic THz journal—*International Journal of Terahertz Science and Technology (TST)*, and an electronic network for bringing together THz researchers—http://www.tstnetwork.org.

Professor Liu's own research continues to emphasize electron beam structures and devices [50]–[53], but is now also focused on THz effects and applications, especially on surface plasmons [54]–[56] and new material systems like graphene [57], [58].

This past December, Shenggang Liu celebrated his 80th birthday, and 60 years in science. UESTC honored him with an international workshop and a wonderful gala birthday celebration. As a special tribute, the Chinese Academy of Sciences released a set of two books covering Shenggang Liu's life [59] and honoring his technical career [60].

In closing off this interview, I asked Professor Liu what he might say to prospective students who wished to follow in his footsteps. He answered with three crisp mandates, "You must truly be interested in your chosen field of study, you must work very hard, and you must not be afraid to put your work first, *above all adversities*."

What might we say about Professor Liu: "For sixty years you have done just that!"

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[3]Since 2004, this conference series has merged with the *International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*.

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