

Glimpses from a Lifetime in Teaching and Research



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The First Two Years

I joined the profession of teaching and research, by choice, in December 1961 and continued regular teaching till December 2010. That makes a total of five decades in teaching. The research activities started in early 1960 and I am still continuing, which makes five decades and a half in research, at the present time. Immediately after obtaining my M.Sc. (Tech.) degree in Radio Physics and Electronics (RPE) from the Calcutta University in 1959, I joined the River Research Institute (RRI), a West Bengal Government Organization, as the Research Officer (Electronics). My job was to conceptualise, design, and fabricate transistorised instruments for measurements in hydraulic research. Transistors did not figure at all in the syllabus of RPE those days and all that I knew about transistors in student days was from a few lectures delivered, at the request of students, by Dr. A. N. Daw, who was a Lecturer at that time and had done his Ph.D. on transistor theory. At the RRI, the new job, the first in my life, forced me to learn transistor circuits by studying very hard, and experimenting with transistors, and, of course, burning a few of them. The only transistors available in the market at that time were OC71 and OC72, made by Philips, and I had to be content with whatever their capability was. I did design and fabricate a transducer for water level recording, and the associated signal processing circuits, by using transistors and diodes; a complete electrical analogy experimental setup; and a transistorised setup for field measurement of soil permeability. All the three developments appeared in the journal *Irrigation and Power*, published by the Central Board of Irrigation and Power, New Delhi. A theoretical analysis of the water level recorder and a method for linearizing the response also appeared in the *British Journal of Applied Physics*.

At RRI, I also started research on network theory and transistor circuits. The initial studies were concerned with analysis and design of frequency selective RC networks and transistor oscillators. In these efforts, I received tremendous support and encouragement from Professor A. K. Choudhury of the Institute of Radio Physics and Electronics (INRAPHEL), fondly known as AKC by his students. Some of this work appeared in the *Indian Journal of Physics* [1] (Numbers within square brackets refer to the corresponding numbered end note) and *Journal of the Institution of Telecommunication Engineers* [2].

At the University of Kalyani

Towards the end of 1961, I realized that my interest in network theory, and my ambition of acquiring a doctorate degree, could not be pursued with full vigour in parallel with the instrumentation work at the RRI. This got coupled with my life's ambition of ultimately joining the teaching profession, and I started exploiting the possibilities. On advice from a friend, I met Professor S. K. Mukherjee, the highly reputed and respected Chemistry Professor, who had just left the Indian Association for the Cultivation of Science

to take up the position of Professor of Chemistry and Dean of the Faculty of Sciences at the newly established University of Kalyani. This meeting is memorable because the next day he sent me to meet the Vice Chancellor and a few days later, I received an offer of Lecturership in Physics at the University. I of course accepted it with pleasure and joined the job soon thereafter. I had to teach Physics as a minor subject to B.Sc. Chemistry Honours students. This was the first year of the first undergraduate program started by the University. Physics Honours program started a couple of years later when Dr. D. P. Ray-Chaudhuri joined the University as a Reader. While there were only three students in the B.Sc. Class, I also had to teach a Physics course to 60 odd students of the first year B.Sc. (Agriculture) program under the Faculty of Agriculture. The Faculty of Agriculture was inherited by the University from the erstwhile Birla College of Agriculture under the Calcutta University and was well established and reputed with undergraduate and postgraduate courses in all branches of Agriculture. I was only 24 years old at that time and had a dozen or so young and freshly graduated lecturers in the whole University to keep company. While my Chemistry boys were overly quiet and eager to learn, the Agriculture students were rather noisy and disinterested in the subject. Being the only Physics teacher in the University, my teaching load amounted to 16 to 18 hours of contact per week, typically 6 hours of theory and 10 to 12 hours of laboratory; however, coping up with this load was not a problem. Soon I devised, in consultation with some colleagues of the same age group, several techniques of controlling a large class, the foremost being to build a personal rapport with individual students. I soon developed the reputation of being able to address each student by his first name when asking questions in the class [3]. The other thing that I practiced is that since I was the one who set up the question paper and also grade the answer scripts, I was not obliged to cover the total syllabus, and therefore not in a hurry. Instead, I took time to explain the concepts in as simple a manner as possible in the class, without referring to notes or books, and adding wit and humour to the rigours demanded of a Physics course. I worked out, in the class, problems which cannot be solved by routine application of formulae, but required an understanding and application of the basic concepts [4].

At the end of the first semester, the informal feedback from the students to the Dean and other senior faculty were appreciative of my teaching and I felt happy. I started the second semester without any feeling of strain, and with enjoyment of what I was doing [5].

At the University of Kalyani, I continued my researches in network theory and transistor circuits. At that time, the problem of isolation between two components in an integrated circuit (IC) fabrication was being seriously investigated. The limitation of space gave rise to the isolation behaving as a distributed RC (RC) network. This was considered as a parasitic and attempts were being made to minimize its effects. I have always been fascinated by distributed networks, transmission lines in particular, and studied the few papers which appeared in IEEE and other journals on the analysis and behaviour of RC networks in ICs, and the possibility of using this network for useful purposes. I did some work on this topic along with transistor circuits, and circuit modelling of transistor action. Interestingly, I established that transistor action can be modelled as that of an active RC network. This work was published in the *International Journal of Electronics*. I also found that inductance, which could not be fabricated in ICs due to space limitations could be realized by using the input impedance of two transistors in the Darlington connection and that along with the inductance, there also appeared a negative resistance in series with it under certain conditions. This opened the possibility of realizing an oscillator by connecting a capacitor across the input. I was excited with this discovery and tried to verify the phenomenon experimentally. Since there was no facility at the University of Kalyani, I used to go to Calcutta every Saturday afternoon (Saturday used to be a half working day those

days), work in the Solid State Circuits Laboratory of Professor A. N. Daw of the INRAPHEL Saturday evening; spend the night in the Law College Hostel on College Street as a guest of one of my Ramakrishna Mission friends; work the full day of Sunday and take a late evening train back to Kalyani, to be present in the class on Monday morning at 10 AM. This routine continued for next few years.

As is well known, making a sinusoidal oscillator is rather tricky, particularly with a two terminal circuit. After a few initial problems of biasing and adjustments, one late Sunday afternoon, it was a moment of great joy for me when I observed beautiful sinusoidal oscillations in the oscilloscope connected across the external capacitance. The parameters of the active inductance were strongly dependent on the temperature. I put the whole circuit in a glass test tube and immersed it in a temperature controlled water bath and took data on the frequency of oscillation vs. temperature. The results were published in *Proceedings of the IEEE* as a letter.

At this time, there appeared in the literature a few papers on the theory and applications of uniform as well as non-uniform RC networks, to be abbreviated henceforth as URC and NURC networks, respectively, and it was shown that using NURC networks, one could achieve several advantages over the URC networks. I investigated the phase shift oscillator application of the exponentially tapered NURC network, theoretically as well as experimentally (the latter by modelling the NURC network by a multi-section ladder network) and published the results in *Proceedings of the IEE*. I also investigated null networks using NURC networks, and compared the results with bridged and shunted RC ladder networks, which acted as the inspiration for replacing RC ladders by RC networks. A paper on this investigation was prepared and published in *IEEE Transactions on Circuit Theory*.

I also investigated some specific exactly solvable NURC networks and formulated a general procedure for obtaining the matrix parameters of a general NURC network in terms of the two independent solutions of the second order differential equation with variable coefficients governing such a network. These results were also published in *IEEE Transactions on Circuit Theory*.

I compiled all this work in a thesis entitled "Some Studies on Lumped RC Networks, Distributed RC Networks and Solid State Circuits" and submitted the same for the D.Phil. degree of the Calcutta University in 1964. The degree was granted in the middle of 1965, but before that another major event occurred in my life.

Distributed RC Networks formed a hot topic at that time. My publications in IEEE and IEE journals attracted considerable attention amongst the circuits community. When I was busy compiling and typing out my thesis, a pleasant surprise waited for me one evening when I returned home after attending college. This was an aerogramme from the United States written in long hand by a young Assistant Professor of Indian origin, B. A. Sheno (BAS) of the University of Minnesota, exploring the possibility of my joining him on a research Fellowship to assist him in his U. S. National Science Foundation project on RC networks. Since I was already preparing my doctoral thesis, and I would not like to go abroad for another Doctorate degree [6], the only way I could honour this unsolicited offer was by accepting a Post Doctoral Fellowship (PDF). However, my sixth sense told me that PDF would be totally under the control of a particular faculty, in which situation, the possibility of intellectual exploitation cannot be ruled out [7]. In reply to BAS, I wrote that I was about to submit my doctoral thesis and that I would be agreeable to collaborate with him in the project as a co-investigator only if I received an offer of a Visiting Assistant

Professor from the University and I underlined the word 'only'. BAS was a very nice human being, and foreseeing that processing such an offer by the University may not be easy and may take time, he was generous enough to suggest that I explore such a possibility with a few other U. S. Universities and he suggested three, in each of which there was at least one faculty member who had research interests in RC networks. I of course knew about their work through their publications. I wrote to the Department Heads of these three Universities, and surprise of surprises, all of them responded positively and enthusiastically within a span of two to three months. Two of them made concrete offers while the third said the offer was under processing and would be mailed in a few weeks' time. It was at this juncture that the Minnesota offer came, but the salary there was the lowest of the three. However, in appreciation of BAS's generosity, I accepted the Minnesota offer and ended up at the Minneapolis airport on a cold night of September in 1965.

At the University of Minnesota

Going abroad was not an easy job for me because I had no reserve money to pay for the airfare. I had to borrow money from a friend and a relative, which of course I paid back within a span of one year. This was my first journey out of the country and that too, to the most advanced and glamorous country in the world. There were many cultural shocks waiting for me, the first one being that the door opened automatically as soon as I stood before it at the John F. Kennedy International Airport, New York! This was a kind of magic to me who had never witnessed anything of this sort earlier in India.

It is important to mention here that I never had settling in the US in mind and this is why I went on two years' extra-ordinary leave from the University of Kalyani. I extended my stay by another year, still on leave, for reasons of completion of the project and completion of M.S. and Ph.D. Dissertations as well as term papers of some non-thesis option M.S. students I was involved in supervising, some jointly with BAS, and a few singly. One of these term papers on inductance simulation by a single operational amplifier, by D. F. Berndt, was published in the *IEEE Journal of Solid State Circuits*; this paper is now considered as a classic, widely applied and cited. On the basis of the research done at the University of Minnesota, I published, singly as well as jointly, papers in *Electronics Letters*, *Proceedings of the IEE*, *Proceedings of the IEEE*, *Journal of the Franklin Institute*, *IEEE Transactions on Circuit Theory*, and *IEEE Transactions on Education*.

At Minnesota, I taught courses on Linear System Analysis and Circuit Theory at the UG level and Network Synthesis and Distributed Networks at the PG level (called graduate level in the US). While I was quite comfortable with Circuit Theory and Distributed Networks, I had to learn Linear System Analysis and Network Synthesis virtually from scratch. I was taught transform techniques at the INRAPHEL by a Mathematics teacher from outside the institute, but he could not create any interest in the subject because he virtually copied the material from the book of L.A. Pipes on the board, in the name of teaching. I was also familiar with elementary network synthesis taught by Prof. A.K. Choudhury in a span of ten lectures, but the University of Minnesota course was a three quarter sequence, going into details and depths. While I was forced to learn the two subjects, I started enjoying the concepts and innovating upon the proofs and application oriented examples.

At Minnesota, I also attended the lectures of a few reputed teachers of the Department, not only to broaden the horizons of my knowledge, but also to become familiar with how teaching is done in the US. I learnt a few novel methods of teaching and

evaluation. One of them is the practice of daily quizzes at the beginning of every lecture, lasting for not more than ten minutes. True, they consumed part of the class time but the benefits to the teacher and the taught were disproportionately large. In every class, the first thing the Professor did was to pose a problem on the board and ask the students to solve it in a given span of time, typically ten minutes or less. While the students were busy in tackling the problem, the Professor would distribute the graded answer papers of the previous quiz and any handout he or she wished to give to the students. The daily quiz problem was not a routine one, but could be solved easily if the student had followed the previous class lecture seriously. This practice could be implemented in a small class of ten to thirty students, because a large class would mean loss of some more time in collecting the answer scripts (typically a single page, which every student was expected to keep ready); also grading them before the next lecture may pose a burden on the teacher. I practiced this daily quiz routine in small classes later at IIT Delhi with very satisfactory results. Initially, the students did not like it, but as the semester progressed, they came to realize the benefits of continuous preparation and serious attention to the class material made them learn the concepts behind every development and enjoy the subject. For the teacher, it is a boon because it gives instant feedback and almost 100% attendance. Nobody can afford to miss a lecture because the daily quizzes carried 15-20% weight in the final grading of the course.

Another new thing I learnt at Minnesota was that of open book, open notes examination. I adopted this in my teaching immediately and since that time I do not remember to have given a single closed book, closed notes examination. This was unheard of in our student days and at IIT Delhi, I had to face much criticism and scepticism from my colleagues on this count. Some examinations at Minnesota were take home types, i.e. the student takes the question paper home, consults freely source materials and even people, prepares the answers and submits the next day. This entails hard work on the part of the teacher, and can be practiced in small classes, like an elective or a graduate course with no more than ten students. While take home examinations could not be practiced at IIT Delhi because of many reasons, including larger class sizes, open book, open notes examinations became the SCDR brand. Naturally, the questions had to be set in an innovative manner involving application of basic concepts rather than calculation from a formula or following an algorithm. I also practiced setting up new problems every time I repeated a course. Thus solving a collection of problems set up in the previous sessions gave the students a feel of the type of questions but not any specific question which may figure in the next question.

Leaving the University of Minnesota

In the middle of my third year at Minnesota, the Head of the Department, Professor R. J. Collins (RJC) asked me if I would like to be tenured as an Associate Professor in the Department and I told him "Thank you Bob, for your consideration, but I have to return to India and struggle it out there". He appreciated my sentiment, but also told me that his door will always be open in case I wished to return. Soon after this, some quick developments took place. One day RJC brought to my notice an advertisement for faculty positions at IIT Delhi (IITD) and a letter to him from Professor P. V. Indiresan (PVI), the Head of the Department there. RJC asked me if I was interested, and I said, "of course", because getting to teach at an IIT would be a great opportunity for working in the main stream of my background as compared to going back to Kalyani and continue teaching Physics there. Things moved very quickly thereafter, ending up in an offer from IIT Delhi as an Associate Professor in about three weeks' time. By that time, I had already written to three other IITs and the University of Roorkee. It was my good luck that I got a telegraphic

appointment from one IIT and a positive response from the other two, one short of making a formal offer and the other saying that the processing would take some time. I also got an offer from the University of Roorkee, and a surprise offer from the Calcutta University. It was a surprise because I had never written to Calcutta University, the reason being that I never wanted to go back to my alma mater where I would be amidst all my former teachers. When I was tossing with the various offers, a personal letter came from PVI urging me to accept IITD offer and join as soon as possible. This was followed by an aerogramme from him almost every week. Even though the IITD offer was attractive, I hesitated because I came to know that one of my seniors at INRAPHEL, A. K. Mahalanabis (AKM) had joined IITD as an Assistant Professor. A letter from him dispelling my discomfort and urging me to help him in initiating research at IITD settled the issue, and I landed at the Delhi Airport in the early morning of 23rd September 1968. I was received at the airport by PVI himself with a staff car and after dumping the luggage at the Institute Guest House, I went to the Department to give the joining report.

This was the beginning of a relationship for the next 42 years. I have been associated with IITD, initially as an Associate Professor (September 1968 - December 1969), then as Professor (January 1970 - July 1998), Head of the Department (1970 - 1972), Dean of Undergraduate Studies (1983 - 1986) Emeritus Fellow (1998 - 2005), Indian National Science Academy (INSA) Senior Scientist (2005 - 2007), and finally as INSA Honorary Scientist (2007 - 2010). For the last two positions, there was no financial obligation of IITD. In between, I spent a year as Visiting Professor at the University of Leeds, on deputation from IITD under the Imperial College-IITD Exchange Program and a year at the Iowa State University, USA, on sabbatical leave.

Because of the space limitation, it is not possible to give a total and detailed account of my teaching and research experience at IITD for such a long time in this presentation. I shall therefore record here only some interesting events and experiences during the initial years. I hope to supplement this narrative in a future article if such an occasion arises.

The Initial Period at IIT Delhi

The first thing that struck me odd at IITD was the B. Tech. Curriculum. Having been familiar with subject based courses like Circuit Theory, E. M. Theory, Communication Engineering etc., it was a shock to me to see that most of the courses taught at IITD were named Electrical Engineering I, II, III etc., each course being a mixture of disjoint topics and taught by three or more faculty members. For example, the first course I was assigned was one in the third year second semester which contained network synthesis, electronic circuits, control and communications, and was taught by four teachers. I was asked to teach the network synthesis part. This combination was a continuation of the third year first semester course. Later, when I was in Leeds for a year, I found the same pattern of courses, and I realized the reason for the curriculum at IITD. Having been started in collaboration with Britain (Imperial College, in particular), the British pattern was followed *in toto*. In fact, all the founding Heads of Departments as well as other Professors (one or two in each Department) at IITD were Britishers. Not all of them were good academics; in fact, the rumour at IITD was that this place was the dumping ground for UK Academics who could not make much dent in their own country. Many of them did not even have a Ph.D. degree, and even the ones who had a Ph.D. degree had poor research credentials. The background of one UK Professor was high school teaching, and when he returned to UK after the IITD assignment, he had tough time in getting a suitable job. This explains the poor research ambience prevailing at IITD at that time.

In the first faculty meeting that I attended, I expressed my disappointment at the course curriculum and emphasized the need for a revision so that the curriculum falls in line with modern ones followed globally, even in other IITs in India. Most of the faculty agreed with me outside the meeting, but they hardly spoke at the meeting. Needless to say, I felt uncomfortable with their silence in the official forum, and kept repeating the need for restructuring in subsequent meetings. An exercise in this direction started, and when completed, had to face opposition from the Senate for approval. Many Senators, particularly the Britishers, and the UK trained Indians argued that there was nothing wrong with the existing curriculum. Anyway, ultimately it was implemented after about two years, in the Electrical Engineering Department to start with, and gradually, other Departments fell in line.

The research ambience in the Department was also very disappointing. At the time I joined, there were only two full time research scholars, both under the supervision of PVI, although there were twenty five or more faculty members in the Department. Besides PVI [8], there was only one other Professor, C. S. Jha (CSJ) [9]; there were a few Assistant Professors, but the majority were Lecturers. Most of the Lecturers were Master's degree holders and a few only had a Bachelor's degree. Some Lecturers were registered for their Ph. D. with AKM in the area of control [10].

I was promoted to full Professorship in January 1970, and soon thereafter, I was appointed Head of the Department at the age of 32 years! I was the youngest faculty in the Department, and there were quite a few faculty who were much older than me. I was then deeply involved in research with a faculty member and a regular research scholar who registered with me for Ph. D. Also, I had no administrative experience at all. I therefore requested the Director, Professor R. N. Dogra (RND) to excuse me and ask either PVI to continue or give the responsibility to CSJ who had done it earlier as the second Head of the Department after Professor John Brown, the founder Head. CSJ also served as a Dean and was responsible for introducing (rather kind of forcing) the rotating Headship system in the EE Department at IITD (as well as in IIT Kharagpur when he went there as the Director), which was later adopted as the Institute policy. He as well as PVI simply refused to step in as Head for another term; they in fact insisted that I should take over. AKM was the next senior most in the Department but RND would not simply give it to an Assistant Professor because in his opinion, that would create a bad precedent [11]. I therefore found no escape route and had to accept. CSJ and PVI fully cooperated with me and all major decisions for the Department were taken by the three of us (This, incidentally, was the beginning of the concept of a Professorial Committee in the Institute, which was later adopted formally by a resolution of the Senate). If I needed some extra funds for the Department beyond the budgeted amount (which was a petty one because the country was undergoing financial crisis for quite some time), we three used to go together to RND for sanction. After a couple of occasions like this, RND would listen to one of us and simply ask for the paper to put his signature if he considered the amount reasonable. He branded us as the 'Trimurti' and would quote this harmony amongst the Professors as exemplary, to other Departments as well as in the Senate. This harmony was not there in most of the other Departments, and in some Departments, a change of Headship was usually accompanied by pinpricks and sufferings for the previous Head! In fact, this, coupled with the charms of power and authority, was responsible for many ex-Heads to start new centres in the Institute, in the guise of intensive research and development in a focussed area. As is well known, most centres either became Departments or duplicated all the activities of a Department including teaching programmes, in due course of time.

Amongst all this craze for power and authority, I appeared to be an exception, and

was mostly pitied upon by my colleagues, but also appreciated by some, particularly younger faculty because I had no such ambition. The Headship was imposed on me due to circumstances prevailing at that time. I had to accept the Deanship at the persuasion and insistence of the then Director, Professor N. M. Swami who was a dear friend and colleague, and Head of the Textile Engineering Department when I was the Head. I was offered Deanship and Deputy Directorship several times in my career by successive Directors but except for this one time, I politely declined every time. The exception I made was at the advice of my wife who told me, "Why don't you do it once so that nobody can say that you shirked responsibility?" The reasons for my averting administration are twofold. Firstly, I feel that I do not have the aptitude or the tact and diplomacy to carry out an administrative responsibility successfully. Secondly, I always felt frustrated when administrative duty interfered with my passion for research and interaction with students. Successive Directors of IITD as well as some other IIT Directors nominated me for Directorship of IITs without my knowledge several times, but every time a query came from the MHRD regarding this, I politely told that I am not interested. I have no regrets on this count because I feel that I have lived a full and enjoyable life in the teaching and research profession. I also feel that even without holding an administrative office, I have been able to contribute to streamlining some aspects of administration, particularly for enhancement of the quality of education not only in IITD, but also in several other national institutions, without expecting any returns in terms of power or fame.

Returning to my Headship days, I must admit that I had a tough time in keeping the faculty together and carry out academic reforms. Right or wrong, I used to encourage every faculty to speak frankly, even criticising me, in faculty meetings, as well as in personal interaction, but insisted that all differences should be sorted out in the Department itself and not spread outside. By and large, I had moderate success in persuading many of the colleagues to fall in line with the culture of a modern Department. Let me cite an interesting example.

Immediately after taking over as the Head, I made a proposal to RND to allocate a dozen of research scholars for the Department. The first question he posed to me was "Who is going to supervise them? After all, you are only three Professors!" I had hard time to convince him that any Ph.D. qualified faculty should in theory be able to guide a research scholar, and I would assign research scholars to every such faculty, irrespective of whether he is a Lecturer or a Professor. It is worth mentioning here that RND was a Chief Engineer in PWD Punjab and was deputed first to Punjab Engineering College as Principal, and then to Delhi College of Engineering, which gave birth to IIT Delhi, where RND became the Director. He did not have deep knowledge of the academic world, and my arguments were not successful in convincing him fully. After some more discussions he agreed for ten scholars. I recruited them in due course and assigned them to each Ph.D. qualified colleague of mine, by trying to match the interests of the faculty and the student. Would you believe that most of these colleagues were unhappy and considered this step as imposition on their academic freedom? One of them stormed into my office and shouted, "Who do you think you are that you can order me to guide a research scholar?" I tried to argue with him that IIT is not an ordinary engineering college and that research and development are essential mandates of the IIT faculty, but failed to convince him. Several other faculty followed his step, and I succeeded in getting six scholars accepted. The rest four had to get registered with me, making a total of six or seven Ph.D. students. Coupled with administrative responsibilities and regular teaching, this indeed posed a heavy load, but I somehow survived, and gave no opportunity to my research students to feel that I did not give them adequate time. I could feel the good effects of the so-called 'imposition' by the time I relinquished Headship. Because of the compulsion, new supervisors had to get

interested in research and started publishing in IEEE and other reputed journals. By this time, the number of regular research scholars in the Department had doubled, and the initially reluctant faculty also started guiding research. Immediately after taking over as Head, I had put up a notice board for posting recent journal publications of the faculty and put up the first page of some of my recent publications there. By the time I left the Head's office, the Board was already full and we started removing some of the oldest ones to make space for the new ones.

At IITD, one of my lecturer colleagues, S. N. Hazra (SNH) who had a B.Sc. Degree of the University of Edinburgh, wished to register with me for the Ph.D. degree. I agreed and advised him to start studying active RC filters, a topic in which I and most of my research students were working. No, he did not want to work on this topic, but his choice was digital signal processing (DSP) and digital filters, in particular. Except for a pedestrian acquaintance with sampling and z-transforms, I knew very little of the subject. At that time, DSP was in its infancy, and I declined the request of SNH. He was not prepared to take a 'no' for an answer, and kept on insisting. He assured me that we would learn the subject together and that he would not demand much of my time. I finally gave up, and agreed. In retrospect, I think this was another turning point in my research career because the subject of DSP occupied most of my attention in later life, and continuing even today.

There was only one book at that time on the subject, written by C. F. Rader, which was not a comprehensive one, and we had to do a lot of library work to search for and collect research papers on the subject. The collection was a fairly difficult task because there was no photocopying facility either in the Institute or outside, and the Library collections were limited. We had to make requests to the authors by air mail, and fortunately, most of them responded positively. Compared to today's online availability of research papers even before they are published and almost instantaneous transmission by internet and e-mail, we appear to have used pre-historic methods, but this had its own positive points. We valued the knowledge earned through such hard work and the retentivity was unbelievably large [12]. Ultimately, we could find some problems to work on, some being extensions of analog filter work I had done earlier.

I organized a Summer School on Network Theory in which SNH delivered some lectures on DSP, and this matured into a full-fledged course on DSP offered by the two of us as an Elective for the Fourth year B. Tech. Students and beginning M. Tech. Students. We learnt more as we taught, and I have no hesitation to confess that I learnt much more from SNH than what he learnt from me. This was perhaps the first formal course on DSP offered in India. SNH got the Ph. D. Degree of IITD in three years' time; again, this was the first Ph.D. granted in India in the subject.

At the University of Leeds

Towards the end of 1972, the Director proposed to send me on deputation to UK under the Indo-UK collaboration scheme. I agreed and chose the University of Leeds as the base station because of the presence of Professor J. O. Scanlan and Dr. J. D. Rhodes, both reputed scholars in circuit theory and distributed networks, there.

My experience in UK during the initial few weeks was not pleasant, but once I settled at Leeds, I could pursue vigorous research, making up for the lost time while doing Headship. There was no e-mail those days, and I continued guiding the scholars at Delhi through regular air mail correspondence. I had no teaching responsibility at Leeds, but gave some special lectures to the students and faculty there on my recent researches.

Thanks to the British Council, my visit was widely publicised and I started getting invitations from various Universities and other research organizations for lecture visits. Besides Imperial College London, I visited the University of Sheffield, City University London, University of Bradford, University of New Castle upon Tyne, Post Office Research Centre at Dollis Hill, London, the General Electric Research Laboratories, and also the IEE Headquarters at London. I made personal acquaintance with many reputed scholars whom I knew and interacted with professionally through correspondence earlier. Also, on invitation from the Sir George Williams University (now known as the Concordia University), Montreal, Canada, I went there on a three day visit and gave as many lectures.

Except for the social ambience at UK in general, and in Leeds in particular, where the skin complexion was a dominant factor in deciding how the ordinary Britisher would treat you, the Leeds visit was professionally very rewarding, in terms of the quality and quantity of research and exchange of ideas with leading experts in my field. Just to mention one example of racial bias, a doctor under the National Health Scheme who treated my one year old son for fever and cold saw my official address as the University of Leeds, and asked me if I was a student. I said, very innocently, "No Doctor, I am a Visiting Professor for a year from IIT Delhi". He could not believe that a non-white young fellow like me could be recognised as a Professor in a UK University. He raised his eyebrows and said, in Sherlock Holmes style, "Professor? That is quite singular!" and asked, "So who do you work for?" By that time, I got irritated and quipped back, "No, doctor, I don't work for anybody. I work for myself. I am an independent researcher". I then showed him my identity card issued by the University with the designation written there. He simply said, "I am sorry", and that too in a rough tone!

At the University of Leeds, I became aware of the bucket brigade device (BBD) and the charge coupled device (CCD), which had just appeared on the technology scene with great potentials. Some work was going on at UK, and I held discussions with the concerned researchers. I studied the physics of these devices and their signal processing applications. In view of my growing interest in DSP, and finding that the mathematical techniques for handling these two charge transfer devices (CTDs) are the same as those for DSP, I got interested to work on the topic. On my return to IITD, I held serious discussions with a colleague, A. B. Bhattacharyya (ABB) of the CARE and found that he was already interested in the device and had a project on Analog Signal Processing Systems (ASPS) which included fabrication and applications of the CTD. I became a Co-investigator in this project and took a Ph.D. student jointly with ABB to work on the fabrication of CCD, and two Ph.D. students singly to work on the compensation of the charge transfer inefficiency of the device, and its applications. The first student ultimately made the first CCD in India at the IC Laboratory, and the other two succeeded in finding new avenues for signal processing applications.

More to Come Later

I have many more stories and events during the rest of the period I spent at IITD, viz. 1975-2010 but I shall reserve these for part II of this article which I plan to write in future. At the present time, let it suffice to say that even though I formally retired in 1998, I continued regular teaching till 2010 at IITD, the last few years being without any remuneration either from the IITD or INSA, when I was an INSA Honorary Scientist. Unlike many of my former colleagues, I did not accept any lucrative assignment in any private institution after retirement, and my decision seemed to be a correct one, in view of the drastic difference in the ambience and freedom existing in such institutions and the IITs,

which I came to know directly and indirectly during the pre-retirement days. I now work from home with virtually pen and pencil and limited computer facilities, but I must say that I am fully satisfied with the way I have lived so far. It is not that I have not committed mistakes, but I have tried to learn a lesson from every mistake I made. Also, my Ramakrishna Mission background gave me the confidence to face difficulties in life bravely and to do good to others as best as possible without expecting any return. After my formal commitment to teaching ceased, I missed the interaction with students for quite some time, but nature took care to fill up the sense of void by various national honorary assignments in educational and research organisations, like Visitor's nominee in IITs and NITs, visiting Honorary Professorships, academic committee memberships of a number of defence organisations, assessment and selection of scientists in CSIR, DRDO etc. I have also found more time for participating in activities of some professional societies and academies in science and engineering and also to pursue my other hobbies like classical music, reading poetry and sometimes writing one or two. My latest venture is to start a journal of the Indian National Academy of Engineering (INAE), to be named *INAE Letters*. I wish to record all these in future.

In Conclusion

I would like to conclude this part of the presentation here. Looking back from the current time to the beginning of my career, I feel that I have lived a full life, with contentment and happiness. I have had many honours, awards and recognitions throughout my career, some sought after, particularly at the beginning of my career, but several others coming as surprises. However, the recognition that I value most is the love and affection of a large number of students, whom I had the privilege of interacting with personally, and also an equally large (if not more) number of virtual students spread throughout the world, whom I acquired through the five video courses I developed, which are freely downloadable on the YouTube through the efforts of NPTEL, and interacted with through e-mails and chance meetings at odd places. This is what keeps me alive and active, despite my numerical age. Should God destine me to have another life after the current one, and ask me to choose a career, I would opt for teaching and research again, unhesitatingly and enthusiastically!

End Notes

[1] Somehow, the INRAPHEL faculty those days had a great obsession for publishing in this journal.

[2] This later became the *Journal of the Institution of Electronics and Telecommunication Engineers (JIETE)*.

[3] This reputation lasted throughout my teaching career. Even now, after many years, when I meet a grown up person, who does a pronam after announcing that I had taught him or her, I can usually come up with the name quickly by analysing the smile, the manner of talking and the body language. It is not that I do not make mistakes, but they are not many.

[4] Throughout my career, I was lucky enough not to be constrained to cover a certain syllabus, and these simple steps proved to be useful in later life also. Much later, at the University of Minnesota, one of my colleagues who studied at MIT, told me that Professor E. A. Guillemin, a pioneering researcher and teacher of circuit theory used to say, "I am not

here to cover a certain course, but to uncover certain parts of it as best as possible so that what you learn remains with you throughout your future career". I found this matching my ideas one-to-one, and used to mention this at the first lecture of every course I taught.

[5] This feedback, even though informal, was very important for me and provided incentive for doing even better. I have emphasized this at every organization I served. At Minnesota and Iowa, student feedback was a long standing practice, and I learnt there how to do it without any involvement of the teacher concerned. At IIT Delhi, I succeeded in getting this done first in my Department, and later adopted throughout the Institute, but only as feedback to the teacher concerned. Many years later, the Director started issuing appreciative letters to the concerned faculty, but there was no public recognition. Public recognition had to wait for many more years, and I understand that today, the Institute recognises outstanding teachers in every Department every semester through an award. I take this opportunity to emphasize a general principle, viz. that a proper recognition of the good and dedicated work of any individual at the appropriate time goes a long way in shaping the future work of an individual. I remember that at the felicitation ceremony of Professor S. N. Bose after his election to the Royal Society, Professor Bose said, "What use is this recognition at the fag end of my life?".

[6] Somehow, I felt that this does not speak well for the state of education in India, specially the Calcutta University, even though I know many academics in India who take pride in their double doctorate. After all, how many American or European Academics are there with two doctorate degrees, excepting the ones whose second doctorate, usually a D.Sc. is considered a higher degree than the first doctorate, i.e. Ph.D. or D.Phil.?

[7] My decision not to go abroad on a PDF, which, as I said, was dictated by my sixth sense, was proved to be a right one by the numerous cases I observed at the University of Minnesota and also later at the Iowa State University. I made acquaintances with many Indian PDFs, mostly in Chemistry, Life Sciences and Physics, and only a few in Engineering. American PDFs were few and far between; PDFs mostly came from under privileged countries like India, Pakistan, nationalist China and South Korea. For an American Ph. D., one or two years as a PDF under the Ph. D. Supervisor was not uncommon, but the longer the person stays as PDF, the less becomes his or her chances of a regular employment as a faculty. For the PDFs from outside US, it is considered as a win-win situation, because they wanted to come to US on some pretext or other, mostly pre- and post-doctoral fellowships, and ultimately settle there for a better life than is possible in their own country. On the other hand, US faculty need assistance in research to increase their publications count and brighten the prospects of getting tenure/promotion/annual increment. In the US, the amount of funds brought by a faculty to the University is a strong parameter in their career progression. They have to depend on talents from abroad, because the percentage of American high school graduates going for higher studies is very small, and the American Graduate Schools survive because of foreign students. Most American students who pursue higher studies quit after the Bachelor's degree. This is perhaps one reason why the Master's degree program there is not as rigorous as it is in India either in duration or breadth. One could obtain a Master's degree in Engineering in the US in 9 months and only on the basis of course work and little or no emphasis on laboratory practice.

The second reason is that the amount of Fellowship to be granted to a PDF depends solely on the Principal Investigator; there is hardly any University or country norm. As a result, the money required to be given to an American PDF can fetch two from India, and the more the manpower, the more will be the volume of the output in terms of

research publications. I know of some Science faculty in US, who employed a large number of PDFs to carry out research for them, and as a result, their publication count was close to, or exceeded a thousand. This phenomenon is of course not rare in other countries, and even in India. The other aspect of Indian PDFs in US I observed is that scientific experiments which required overnight running of a process was mostly carried out by Indian PDFs. I know of many Indian PDFs who run from one University to another again as PDF because the project in which they were employed was over, and there was no guarantee as to when the next project would come. I have known Indians who have spent their lifetime as PDFs and could never get a regular University employment. These are kind of professional PDFs, and I have met some of them, who, out of frustration, returned back to the country at a much lower level of appointment than what they deserved. However, some of them did very well in their later life, and rose to the top echelon in their organization, including the top positions. Many of my readers may differ with regard to their experience of PDFs; what I have stated here is solely based on my experience.

[8] PVI later founded the Centre for Applied Research in Electronics (CARE) at IITD, and became the Director of IIT Madras.

[9] CSJ later became the Director of IIT Kharagpur, followed by Technical Education Advisor in the Ministry of Human Resource Development (MHRD), Government of India, and finally the Vice Chancellor, Banaras Hindu University.

[10] AKM was promoted to Associate Professor during my Headship, and he took over from me as the Head of the Department. He was later promoted to full Professorship. Unfortunately for IITD, however, he left the country and settled in the Penn State University. He died an untimely death in the prime of his career due to cancer.

[11] It may be mentioned in passing that IIT Kanpur had carried out this experiment of making an Assistant Professor the Head of the Department, but the results were not satisfactory, for various reasons.

[12] Perhaps that is how my romance with DSP still continues!
