AMS (Analog and Mixed Signal) Experiences of Dr. Ravi Shankar

- 1971 - Senior Project for BS in Telecom Engineering: Design of a Linear Regulator Power Supply. Met stringent requirements. Best design of the class.

- 1971-73 Technical Officer I, Electronic Corporation of India Limited, India. Responsible for the board-level design of nonlinear functions used in analog computers. Contributed to discrete transistor implementations of operational amplifiers. Developed a folding technique (with digital logic) for multipliers that results in a more compact implementation. Recently (1999) applied for a provisional patent, for use as a special purpose digital multiplier.

- 1974-76 Research Assistant, University of Wisconsin, Madison, WI. Developed an instrument for Cell Electrophoresis, in which high voltage (200 V) is switched under manual control and mobility of red blood cells (RBC) determined. RBCs were suspended in a saline solution in a small chamber, with their motion monitored using a microscope. A Canadian group had determined that cancerous blood cells had a lower mobility.

- 1977-82 Teaching Assistant, Electrical and Computer Engineering, University of Wisconsin, Madison, WI. Taught hands-on laboratories for students and engineers (via Continuing Education Division) on Biomedical Instrumentation (strong emphasis on sensors and analog instrumentation) and Data Acquisition (combined analog-digital systems and interfacing). Developed a pulsed Doppler flowmeter (4 MHz system with a pulse repetition frequency of 100 KHz) for blood flow measurements, and designed an FFT processor for class projects.

- 1977-82 Research Assistant, Electrical and Computer Engineering, University of Wisconsin, Madison, WI. Developed an automatically resetting high sensitivity impedance plethysmograph. This is a noninvasive instrument used to measure blood volume changes in humans and primates. A typical signal is 0.2 mW, 1 to 10 Hz, riding on top of a 20 W dc level. The challenge, similar to the dc receivers in GSM, was to null the dc and amplify the ac signal. It had a (tissue) impedance range of 0 to 63.75 W, a sensitivity of 66 mV/mW, a low-noise output of 0.33 mW, and a frequency response of 0 to 15 Hz. It used a 10 mA, 100 KHz constant current source. Two 10-bit MDACs and two 12-bit SARs served the purpose of automatic resetting. The phase sensitive demodulators were the major contributors to noise. Used the system on the lower legs of 200 human subjects with varying heart disease risk factors and also monkeys, with much narrower limbs. This work led to 3 US patents on early detection of heart attacks (in 1993). Other relevant info: Developed experimental and mathematical models (100 simultaneous differential equations, Runge-Kutta methods) to simulate the heart and blood flow.

- 1982-85 Assistant Professor, Electrical and Computer Engineering, Florida Atlantic University, Boca Raton, FL. Conducted primate studies at Bowman Gray School of Medicine, Winston-Salem, NC. Obtained excellent statistical validation against actual extent of disease obtained after postmortem. Developed courses on 'Data Acquisition and Processing' and 'Introduction to VLSI'. For the latter, used Magic, Crystal, and SPICE.

- 1985-88 Assistant/Associate Professor, Electrical and Computer Engineering, Florida Atlantic University, Boca Raton, FL Developed courses on 'Semi-custom Design with DSP' and 'Computer Design' with DABL. IBM projects with LSSD. Developed a 3-channel data acquisition system around Analog Devices' MACSYM-150, for use in monkey studies. Conducted longitudinal monkey studies. Data collected on 20 monkeys (once every 8 to 10 weeks) was digitized and signal processed using MACSYM. Structured programming techniques used in developing the protocol. A few VLSI designs (analog: 10-bit capacitance array, current mirrors, and differential amplifier; digital: signature analyzer) submitted to MOSIS for fabrication. Translated SwitchCap, a switched capacitor design package, from Fortran to C for use by APTEK Inc.

- 1988-92 Associate/ Full Professor, Computer Engineering, Florida Atlantic University, Boca Raton, FL. Taught courses on 'Neural VLSI', 'Artificial Neural Networks' ,'Concurrent Processing', and 'Digital Hardware Design' using VHDL and Xilinx FPGA. Submitted several VLSI designs with emphasis on analog/mixed signal concepts: A subthreshold analog building block library (current mirror, transconductance amplifiers, follower-integrator, and Gilbert multiplier); A hexagonal array CCD; a VLSI thinning chip with massively parallel architecture. Several projects, funded by IBM, DARPA, and others on biometrics (optical character recognition for US live mail, and artificial cochlea); and SIMD (single instruction multiple data) architecture (for nonpolynomial (NP)-complete problems). Developed a high signal to noise ratio electrical impedance plethysmograph for use on the limbs of pigeons, the current non-human model for heart disease study. The challenge was to amplify the small ac signal in the presence of a large dc signal, before feeding to the noisy phase sensitive demodulator. Decreased the noise by 50%, while boosting the sensitivity 300%. Published a book on "VLSI and Computer Architecture," by Academic Publishers Inc. This book has four chapters, one on each of the then important VLSI technologies (MOS, Bipolar, GaAS, and Superconductivity) and covers the EDA tools with a broad perspective. Explored the use of switched capacitors for implementation of Dr. Chua's Chaotic Oscillator.

- 1993-96 Professor, Computer Science and Engineering, Florida Atlantic University, Boca Raton, FL. Strong infusion of funds and structured design methodology into the curriculum with funds from Motorola and NSF. Established a college-wide center on VLSI and Systems Integration (CVSI). Developed courses on 'ASIC (top-down) design' with Verilog, 'Rapid prototyping', 'Low Power Design', and 'MEMS' (microelectromechanical systems). Incorporated in the design flow tools from Cadence, Cascade, Synopsys, Analogy, HSPICE, Maspar, HP82000, EPIC, and LEdit. Had training on all the tools. Of special mention: Cascade had a retargetable cell library technology that I was trained on. Designed SPI (Serial peripheral interface of 68HC08) and DLX (combined RISC architecture of Hennessy and Peterson) top-down and implemented as an ASIC. Directed the efforts of a 30+ team of engineers and computer scientists in designing a clinical system for clinical validation of my method. This was sponsored by Vasocor Inc., which has since then commercialized my research. This was a highly sophisticated high sensitivity data acquisition system that collected 6 Mbytes of data sampled at 50 KHz from subjects. The system used various digital and sampling techniques to reduce noise and enhance reliability, and bypass traditional analog techniques for applications such as signal generation (similar to the Harris Digital Down Converter, or DDC, discussed below), demodulation (similar to the IBM- proposed SiGe direct sampling of 2.4 GHz ISM/Bluetooth signals), and dc nulling (similar to the method used by a French company in their 900 MHz GSM receivers with dc (direct conversion) used for the RF portion). The data were stored and shipped for off-line digital signal processing that reduced the 6 Mbytes of data to 100 two-byte set of parameters for each subject-visit. Biomedical signals have high degree of variability that makes signal processing highly challenging. Structured design techniques were used for software, hardware (electronics and mechanical) and DSP in the project.

- 1997-98, Professor and Director, CVSI, FAU, Boca Raton, FL. Developed an 'Embedded Systems Design' course based on 68HC16. Developed a methodology to translate SPW-level design to Verilog, for a Harris design (a Digital Down Converter, DDC, essentially a digital mixer). DDC uses several digital techniques, such as sine/cosine generation with ROM tables, high speed multiplier, high decimation filter, and Comb filter. Continued work on analog DFM (Design For Manufacturability): In our earlier work with subthreshold analog blocks, we had noticed that there was much variation in SPICE parameters from run to run, and with our analog designs dependent on second order matching (as with differential amplifier stages), DFM techniques were clearly needed. We repeated and refined the methodology of Dr. Ismail and Nokia. The methodology involved the use of APLAC to run simulations first to center the design and then to desensitize it for manufacturing variations by compensating for SPICE parameter variability (only three key parameters) in the design. In addition, we developed a production method with analog switches and grid array packaging, so wafer probing was not needed. We used Analog Artist for design and simulations, in place of APLAC, during 1996 summer at Motorola. A VLSI chip with differential transistor pairs in various sizes and positions was submitted for fabrication. In addition, we also worked on 'Tarit' vibrator of Motorola and developed a partial electro-mechanical-magnetic model. The study is supposed to help us develop miniaturized versions of the vibrator. We explored the use of Saber, Verilog A and Bond graph theory to represent such multi-disciplinary systems. Further funding is needed for these projects.

- 1998-2000, Professor and Director, CVSI, FAU, Boca Raton, FL. Used Matlab and PSPICE in some power supply design projects to design buck, boost, buck-boost, and cuk type systems. Used PLI for Verilog-C codesign and Ambit for synthesis in my course 'ASIC Design'. Students in the course are developing models/designs at various levels, viz., Matlab, C, HDL (Verilog), ASIC, and VLSI for small subsets of Blue Tooth specifications. I worked on a Motorola project on power supply optimization, with a SABA (Scientific Advisory Board Association) grant from Motorola. With regard to my biomedical research, Vasocor received FDA approval for the method. I have learnt much about IBM's DFM (design for manufacturability) for digital systems.
- 2001-2007, Professor and Director, CSI, FAU, Boca Raton, FL. The center was renamed to emphasize its focus on systems integration issues. We have been funded by Motorola on a project entitled "One Pass to Produciton" (OPP) since 2003 to the tune of $1.035 M in 5 years. The project is expected to continue to be funded for another 3 years. The goal of the project is to reduce the product development time of typical mobile systems from the 24 months it took in 2003 to 24 hours. We have made substantial progress in that direction. Our current estimate, after 5 years of research, is that a one month product development time is entirely feasible. Further progress, over the next 3 years, will be focused on dynamic run-time optimization. This will utilize concepts from adaptive control systems as adapted to multi-core digital systems. Another concept relevant to analog and mixed signal design relates to the development of a component library with annotation required for the OPP flow. Dr. Valentine Aalo, Electrical Engineering, has started working with me in developing an RF component library, with Labview as the platform. Eventual goal is to port these components to the MLDesigner environment, which supports multiple MOC (models of computation).