Preparing Students Equipped with the State of Art Technologies with Appropriate Mix of Fundamentals

Kanti Prasad Ph.D.; P.E.; F.ASEE, Professor Electrical and Computer, Engineering Dept. Founding Director Microelectronics/VLSI Technology, University of Massachusetts Lowell, USA

Abstract—During my teaching career of the state-of-art courses for the last 30+ years, I am convinced that the foundation of any Hi-Tech course lies in the fundamentals. The fundamentals are derived from physics, chemistry, and mathematics. The integration of fundamentals, I plan to depict through examples in three of my Hi-Tech courses I am teaching at the moment namely VLSI Design, VLSI Fabrication, and MMIC Design and Fabrication. Over the years, I also developed and taught Local Area and Computer Networking, Introduction to ITS Technologies, and VHDL Based Digital Design, where I always incorporated fundamentals. Presently, I am also teaching Circuit Theory wherein I emphasize how fundamentals of Circuit Theory serve as backbone for my research on Sensors and Bulk Acoustic Wave Filters presently. Historically about 250 years ago it was only physics and applied physics, which culminated into engineering later on. Engineering then grew into specialized disciplines such as Civil, Mechanical, Electrical/Electronics, Chemical, Material, and Plastics engineering etc.

I. INTRODUCTION

Teaching is a profession of utmost importance. Teacher in Sanskrit means ‘GURU’ (Gu: Ignorance and Ru: destroyer). The sublime duty of instructor therefore is to destroy the ignorance of students and prepare them to meet the challenges of the technologies, which are perpetually evolving. This can be accomplished through integration of fundamentals in the state-of-art technologies so that the contents never become obsolete.

This assures preparing the students for the 21st century so that they can take a suitable place in the technological world, thereby becoming productive citizens in the society.

Teaching however must translate into learning by the students. Whatever new information is being provided in the classroom by the teacher it must translate into knowledge. No new information can become knowledge until or unless it is yoked with the existing database of the students. Teachers must make sure that they continually connect higher with lower database. This is the way to make students wise else they remain otherwise. I repeat this mantra in all my classes, so that no students of mine remain in the otherwise category. Throughout the paper I have included fundamentals which manifests from Physics, Mathematics, Circuit theory, Logic design and Electronics, these fundamentals are included in these state of art technologies comprising VLSI Design, VLSI Fabrication, and MMIC Design and Fabrication, as depicted through examples in the paper. These examples are solely from my class notes.

II. SILICON BASED CMOS VLSI

Since the basic material is silicon, so silicon as an atom based on fundamentals of physics is depicted in Fig.1.

However, as silicon appears in the form of material has the aggregate of atoms it gets hybridized as (s p^3) shown in Fig.2. This makes it an ideal intrinsic semiconductor with $E_g$ of 1.2V.

The Si material needs to be doped with 5th group or 3rd group of the periodic table to make it useful extrinsic n-type or p-type semiconductor respectively. This can further be fabricated as an n-MOS or p-MOS transistor as devices as shown in Fig.3.
III. VLSI DESIGN

Variety of topics pertaining to chip design such as space minimization, speed optimization and minimization of heat dissipation are covered including:
1. Testing methodology with BIST, verification and validation
2. Enhancing speed through software such as Look ahead carry addition and Booth multiplication
3. Design of chips with emphasis on Communication and Controls
4. Built in Self-Test (BIST)
5. Design of Traffic light controller and Illustrative example is chosen for look-ahead-carry adder (CLA).

Example: Derive an expression for Sum ‘S’ and Carryout ‘Cout’ for a 4-bit Look-Ahead Carry Adder for

\[ \begin{align*}
A_3 & \quad A_2 & \quad A_1 & \quad A_0 \\
B_3 & \quad B_2 & \quad B_1 & \quad B_0 \\
C_1 & \quad C_0 & \quad S & \quad Cout
\end{align*} \]

TABLE 1. TRUTH TABLE

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
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<tbody>
<tr>
<td>A</td>
<td>B</td>
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<td>0</td>
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Solution:

\[ C_{out} = \bar{A}B\bar{C}_{in} + A\bar{B}\bar{C}_{in} + AB\bar{C}_{in} + ABC_{in} = (\bar{A} + AB)C_{in} + AB = PC_{in} + G \]

In general

\[ C_{in} = P_{i}C_{i-1} + G_{i} \quad \text{where} \quad G_{i} = A_{i}B_{i} \]

Therefore

\[ \begin{align*}
C_0 & = P_0C_{-1} + G_0 = G_0 \quad \text{where} \quad C_{-1} = 0 \\
C_1 & = P_1C_0 + G_1 = P_1G_0 + G_1 \\
C_2 & = P_2C_1 + G_2 = P_2P_1G_0 + P_2G_1 + G_2 \\
C_3 & = P_3C_2 + G_3 = P_3P_2P_1G_0 + P_3P_2G_1 + P_3G_2 + G_3
\end{align*} \]

\[ S = \bar{A}BC_{in} + \bar{A}B\bar{C}_{in} + AB\bar{C}_{in} + ABC_{in} = (\bar{A} + AB)C_{in} + (\bar{A} + AB)C_{in} = PC_{in} + PC_{in} \]

In general

\[ S_{i} = \bar{P}_{i}C_{i-1} + P_{i}C_{i-1} \quad \text{where} \quad P_{i} = \bar{A}_{i}B_{i} + A_{i}B_{i} \]

\[ \begin{align*}
S_0 & = \bar{P}_0C_{-1} + P_0C_{-1} = P_0 \quad \text{as} \quad C_{-1} = 0 \\
S_1 & = P_1C_0 + P_1C_0 = \bar{P}_1G_0 + P_1G_0 \\
S_2 & = P_2C_1 + P_2C_1 = \bar{P}_2(P_1G_0 + G_1) + P_2(P_1G_0 + G_1) \\
S_3 & = P_3C_2 + P_3C_2 = \bar{P}_3(P_2P_1G_0 + P_2G_1 + G_2) + P_3(P_2P_1G_0 + P_2G_1 + G_2)
\end{align*} \]

It is evident that either in S or Cout, no ripple carry is required. The design of CLA needs lot more hardware. Still CLA is faster than ripple carry adder.
During this course, the author covers a variety of topics including Miller Indices, Photolithography, Oxidation, Diffusion, Ion Implantation, Metallization, Testing, Characterization, Packaging, Reliability and Failure Analysis etc. However, demonstrative example is chosen pertaining to Failure Analysis.

Example:
For a median life $t_{50}$ of 2.1 x $10^6$ hours and a $\sigma$ of 2.0, What fraction of devices would have failed after 10 years of use at 100-degree Celsius. Calculate $E_v$ if the same chip is subjected to 150-degree Celsius where median life drops to 2.5 x $10^4$ hours.

Given:

$$F(t) = \frac{1}{\sigma \sqrt{2\pi}} \int_{0}^{\frac{t}{t_{50}}} e^{-\frac{(\ln(x)-\mu)^2}{2\sigma^2}} dx$$

(1)

$$t_{50} = e^\mu$$

$$\frac{t_{50}@T_1}{t_{50}@T_2} = e^{\frac{E_v}{k}(\frac{1}{T_1} - \frac{1}{T_2})}$$

(2)

Solution:

$$e^\mu = t_{50} => \mu = 14.55745 \sigma = 2.0$$

Let $u = \frac{\ln(t) - 14.55745}{2}$

$$du = \frac{1}{2x} dx$$

$$@x = 87600, u = -1.58845$$

$$@x = 0, u = \infty$$

Substituting in equation (1) we have,

$$F(t) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{1.58845} e^{-\frac{1}{2}(u^2)} du$$

$$F(t)^2 = \frac{1}{2\pi} \int_{-\infty}^{2.5232} e^{-\frac{1}{2} v^2} dv \int_{-\infty}^{1.58845} e^{-\frac{1}{2}(u^2)} du$$

Let $u^2 + v^2 = r^2$

$$dudv = rdrd\Theta$$

$$rdr = dz$$

$$F(t)^2 = \frac{1}{2\pi} \int_{0}^{2\pi} e^{-2z} dz$$

$$[F(t)]^2 = [-e^{-2z}]_{0}^{2\pi}$$

$$[F(t)]^2 = \frac{1}{4\pi} [-0.08020255][-\frac{\pi}{2}]$$

$$(F(t))^2 = 0.02005064$$

$$(F(t)) = 0.1416 \text{ so } 14.16\% \text{ of devices failed in 10 years.}$$

$$\frac{t_{50}@T_1}{t_{50}@T_2} = \frac{2.1 \times 10^6}{2.5 \times 10^4} = \frac{e^{\frac{E_v}{k} \frac{1}{T_1} - \frac{1}{T_2}}}{e^{\frac{E_v}{k} \frac{1}{T_1}}}$$

$$3.676322 \times E_v = 4.4308168$$

$$E_v = 1.20523 \text{ eV}$$

V. MMIC DESIGN AND FABRICATION

In this course, the author covers a variety of topics including connecting ABCD parameters of circuit theory, S- parameters in microwaves, Low noise, High power and broadband amplifiers, oscillators and connection of S-parameters with device physics parameters such as transconductance. However, example is chosen for broadband amplifier.

Example: Design a feedback broadband amplifier with balanced matching networks and couplers.

The circuit arrangement for feedback amplifier is given in Fig. 8 with its model, which is given in Fig 9
Using KVL in terms of y-parameters, with some algebraic manipulations as

\[
S_{11} = \frac{(1 - y_{11}Z_0)(1 + y_{22}Z_0) + y_{12}y_{21}Z_0^2}{\Delta}
\]

\[
S_{12} = \frac{-2y_{12}Z_0}{\Delta}
\]

\[
S_{21} = \frac{-2y_{21}Z_0}{\Delta}
\]

\[
S_{22} = \frac{(1 + y_{11}Z_0)(1 - y_{22}Z_0) + y_{12}y_{21}Z_0^2}{\Delta}
\]

Where \( \Delta = (1 + y_{11}Z_0)(1 - y_{22}Z_0) + y_{12}y_{21}Z_0^2 \), we get

\[
S_{11} = S_{22} = \frac{1}{D[1 - \left(\frac{g_mZ_0^2}{R_2(1 + g_mR_1)}\right)]}
\]

\[
S_{21} = \frac{1}{D\left(\frac{-2g_mZ_0}{(1 + g_mR_1) + \frac{Z_0^2}{R_2}}\right)}
\]

\[
S_{12} = \frac{2Z_0}{DR_2}
\]

where,

\[
D = 1 + \frac{2Z_0}{R_2} + \frac{g_mZ_0^2}{R_2(1 + g_mR_1)}
\]

If \( S_{11} = S_{22} \) as is the case in balanced amplifiers, we get

\[
\frac{g_mZ_0^2}{R_2(1 + g_mR_1)} = 1
\]

Or

\[
R_1 = \frac{Z_0^2}{R_2} - \frac{1}{g_m}
\]

So,

\[
S_{21} = \frac{Z_0 - R_2}{Z_0}
\]

Therefore, \( R_1 \) and \( R_2 \) become,

\[
R_1 = \frac{Z_0^2}{R_2} - \frac{1}{g_m}
\]

\[
R_2 = Z_0(1 + |S_{21}|)
\]

\( S_{21} \) is for overall circuit, not just for transistor only, when both \( R_1 \) and \( R_2 \) are used and \( g_m \) has a very high gain value then \( R_1R_2 = Z^2 \).

This serves as the basic foundation for designing broadband amplifiers. All these examples are given to demonstrate how important are the fundamentals in designing the practical engineering systems.

VI. CORRELATION BETWEEN FUNDAMENTALS AND PREPARING THE WORK FORCE FOR 21ST CENTURY

The technology is evolving all the time, but the fundamental principles hardly change. It is therefore the solemn duty of instructors in the classroom to integrate physics fundamentals in any State-of-Art technology. This will ensure that the engineering students who are product of such teaching methodology never become obsolete. During my own teaching tenure, I have graduated several
hundreds of students who are placed in the high tech industry regionally, nationally and internationally as well, who are vibrant and dynamic throughout their careers as have been found from the surveys of the alumni office.

In fact, I would suggest that engineers in the work environment should even take some advanced technology courses as the time moves. This is a paradigm, which is applicable even to the instructors in each discipline of engineering as the technology evolves in that particular discipline. I would also like to further suggest that the instructors who are teaching fundamental courses should point out some of these fundamentals how germane they are in certain State-of-Art technologies.

In my own case, I also teach Circuit theory, which is the most fundamental course in the curriculum of Electrical and Computer Engineering. I have shown in the classroom, how the measurements of Resonant frequency ‘fo’, the Quality factor ‘Q’ are of paramount importance in designing and testing Bulk Acoustic Wave (BAW) filters for 5G Applications, a research project I am involved at the moment.

VII. CONCLUSION

The technologies are bound to evolve with time based on better modeling techniques. Intricate sound principles are sure to be explored. Therefore, we must teach fundamentals of Physics, Chemistry and Mathematics rigorously and demonstrate continually how the State-of-Art technologies are based on these fundamentals. This is the cardinal philosophy of Innovation in Engineering Education including interdisciplinary approaches to some reasonable extent we must make sure in the class rooms that we emphasize that Physics, Chemistry and Mathematics are the most important tools which are of paramount importance in engineering design.

I am convinced however, that innovations in Engineering Education must be carried out in all disciplines of engineering through integration of fundamentals along with the State-of-Art technologies for the readiness of the work force development nationally as well as internationally to meet the challenges of emerging technologies of the 21st century.

During my teaching these high tech courses I always emphasize on learning. I have positive feedback not only from my students but even from their employers from regional industries such as Analog Devices and Skywork solutions. Most of my PhD students got successfully placed not only in these regional companies but even worldwide such as Intel, TSMC, Global Foundries etc.

VIII. ACKNOWLEDGEMENT

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REFERENCES


