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

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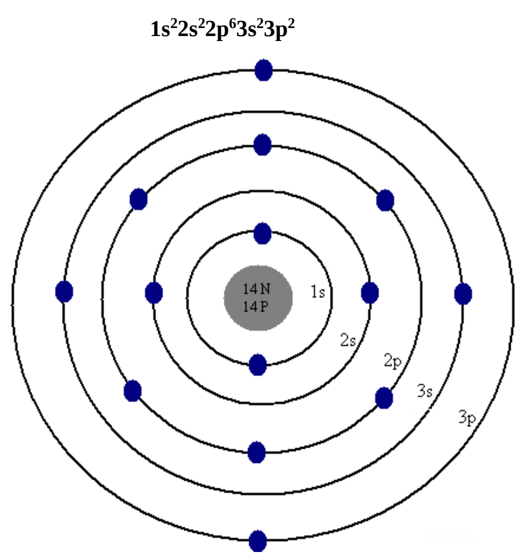
Abstract: During my teaching career of the state-of-art courses for the last 30+ years, I am convinced that the foundation of any Hi-Tech course lies in the fundamentals. The fundamentals are derived from physics, chemistry, and mathematics. The integration of fundamentals, I plan to depict through examples 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.

Keywords: VLSI Design and Fabrication, MMIC Design and Fabrication, Innovations and Engineering Education.

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. 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.

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)

Fig. 1 Si in atomic form

shown in fig. 2. This makes it an ideal intrinsic semi conductor with E_g of 1.2V.

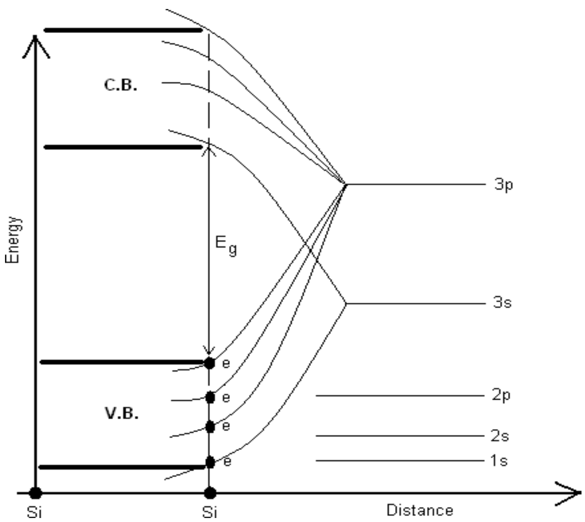


Fig 2. Si in material form

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.

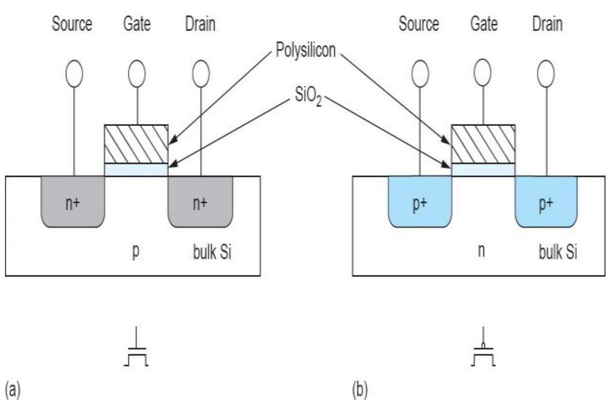


Fig. 3 a) n-MOS transistor b) p-MOS transistor

These devices need to be deployed in making circuits such as an inverter as shown in figure4.

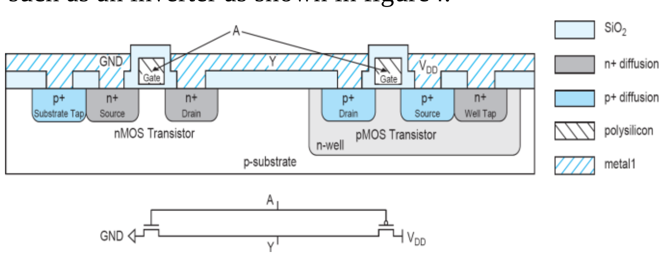
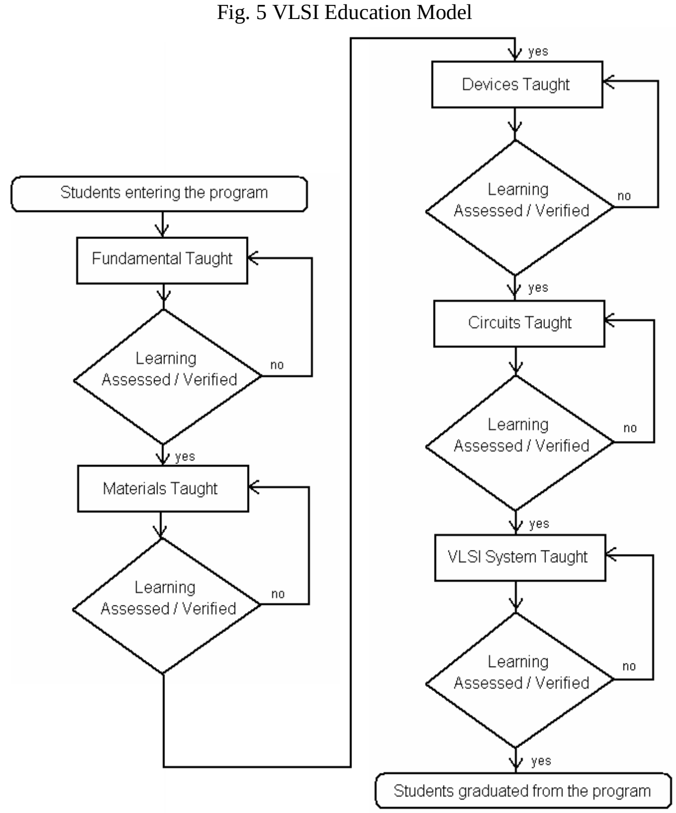


Fig . 4 CMOS Inverter

The consummate VlSI Education Model, which was presented by me at the Canadian Proceedings of Engineering Education in 1998, is depicted in figure5.

Fig. 5 VLSI Education Model



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 'C_{0ut}' for a 4-bit Look-Ahead Carry Adder for

$$A_0\ A_1\ A_2\ A_3$$
$$B_0\ B_1\ B_2\ B_3$$

$$C_3\quad S_3\ S_2\ S_1\ S_0$$

Truth Table:

Inputs			Outputs	
A	B	C_{in}	S	C_{out}
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

Solution:

$C_{out} = \bar{A}BC_{in} + A\bar{B}C_{in} + AB\bar{C}_{in} + ABC_{in}$

$= (AB + A\bar{B})C_{in} + AB$

$= PC_{in} + G$

In general $C_i = P_iC_{i-1} + G_i$ where $G_i = A_iB_i$

Therefore

$C_0 = P_0C_{-1} + G_0 = G_0$ where $C_{in} = C_{-1} = 0$

$C_1 = P_1C_0 + G_1 = P_1G_0 + G_1$

$C_2 = P_2C_1 + G_2 = P_2P_1G_0 + P_2G_1 + G_2$

$C_3 = P_3C_2 + G_3 = P_3P_2P_1G_0 + P_3P_2G_1 + P_3G_2 + G_3$

$S = \bar{A}\bar{B}C_{in} + \bar{A}B\bar{C}_{in} + A\bar{B}\bar{C}_{in} + ABC_{in}$

$= (\bar{A}\bar{B} + AB)C_{in} + (\bar{A}B + A\bar{B})\bar{C}_{in}$

$= \bar{P}C_{in} + P\bar{C}_{in}$

In general $S_i = \bar{P}_iC_{i-1} + P_i\bar{C}_{i-1}$ where $P_i = \bar{A}_iB_i + A_i\bar{B}_i$

$S_0 = \bar{P}_0C_{-1} + P_0\bar{C}_{-1} = P_0$ as $C_{i-1} = 0$

$S_1 = \bar{P}_1C_0 + P_1\bar{C}_0 = \bar{P}_1G_0 + P_1\bar{G}_0$

$S_2 = \bar{P}_2C_1 + P_2\bar{C}_1 = \bar{P}_2 (P_1G_0 + G_1) + P_2 \overline{(P_1G_0 + G_1)}$

$S_3 = \bar{P}_3C_2 + P_3 \bar{C}_2 = \bar{P}_3 (P_2P_1G_0 + P_2G_1 + G_2) + P_3 \overline{(P_2P_1G_0 + P_2G_1 + G_2)}$

It is evident that either in S or C_{out} , no ripple carry is required. The design of CLA needs lot more hardware. Still CLA is faster than ripple carry adder.

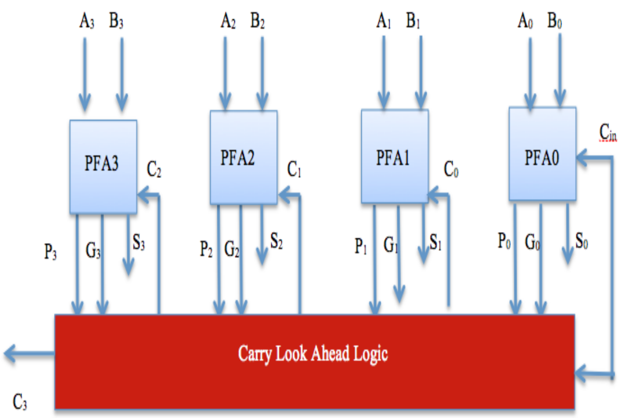


Figure 6 Carry Look Ahead Adder

VLSI Fabrication: 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 of 't_{50}' of $2.1*10^6$ hours and a σ of 2.0. What fraction of devices would have failed after 10 years of use at 100^0Celsius? Calculate E_V if the same chip is subjected to 150^0C, where in median life drops to $2.5*10^4$ hours.

Given: $F(t) = \frac{1}{\sigma\sqrt{2\pi}}\int_0^t \frac{1}{x} e^{-\frac{1}{2}(\frac{\ln x-\mu}{\sigma})^2} dx, t_{50}=e^{\mu}$.

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

Solution:

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

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

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

dx $= x.2.du$

@ x = 87600; u = -1.58845

@ x = 0; u = $-\infty$

F (t) $= \frac{1}{2\sqrt{2\pi}}\int_0^{87600} \frac{1}{x} e^{-\frac{1}{2}(\frac{\ln x-14.55745}{2.0})^2}dx$

F (t) $= \frac{1}{2\pi}\int_{-\infty}^{-1.588457} e^{-\frac{1}{2}u^2}du$

$[F(t)]^2 = \frac{1}{2\pi}\int_{-\infty}^{-1.588457}\int_{-\infty}^{-1.588457} e^{-\frac{1}{2}(u^2+v^2)}dudv$

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

du dv $= r\,dr\,d\theta$

$\frac{2rdr}{2} = dZ.$

$[F(t)]^2 = \frac{1}{2\pi}\int_{\infty}^{2.5232}\int_{3\pi/2}^{\pi} e^{-zdzd\theta}$

$[F(t)]^2 = \left[\frac{e^{-z}}{-1}\right]_{\infty}^{2.5232} [\theta]_{3\pi/2}^{\pi}.$

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

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

$[F(t)] = 0.1416$ so 14.16 % of the devices failed in 10 years.

$\frac{t_{50}@100^0C}{t_{50}@150^0C} = \frac{2.1*10^6}{2.5*10^4} = e^{\frac{E_V}{8.62*10^{-5}}(\frac{1}{373}-\frac{1}{423})}$

$84 = e^{E_V}(\frac{0.0003169}{0.0000862})$

$84 = e^{E_V*3.676322}$

$3.676322*E_V = \ln 84.$

$3.676322*E_V = 4.4308168$

$E_V = 1.20523$eV.

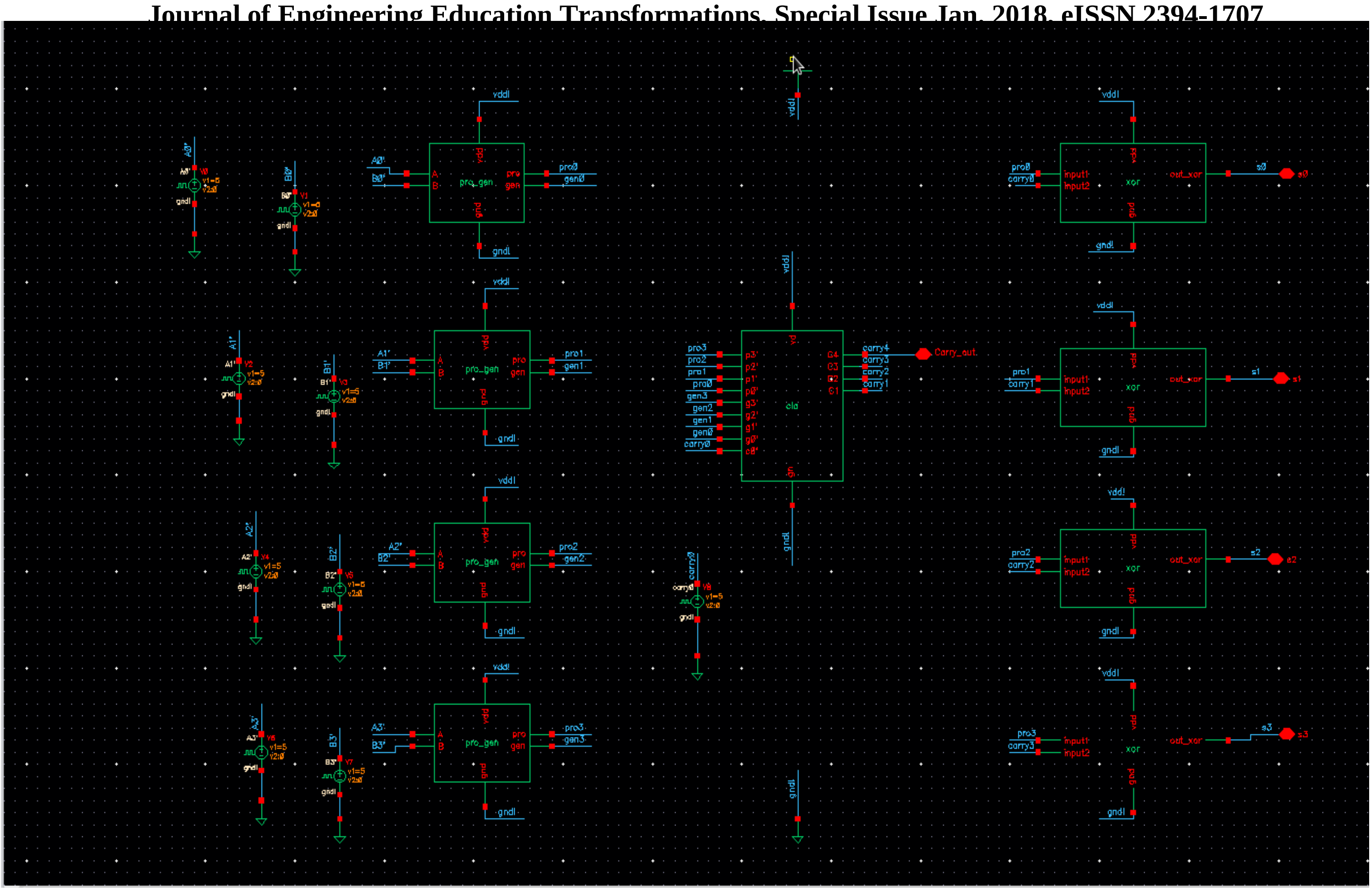


Fig. 7 Carry Look Ahead Adder Schematic on Cadence Virtuoso

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 trans-conductance. 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

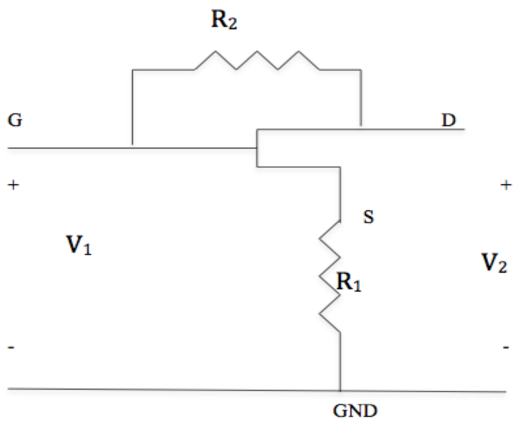


Fig . 8 BB Amplifier

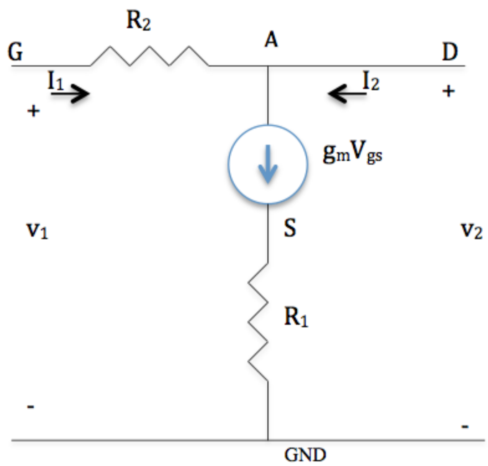


Fig. 9 Model of BB Amplifier

Using KVL in figure 9 around mesh G, S, GND, and G, we get

$V_{gs} + g_m V_{gs} R_1 = V_1$ i.e. $V_{gs} = V_1 / (1+g_m R_1)$ ------------------1

Using KVL in figure 9 around super mesh, we get

$I_1 R_2 + V_2 = V_1$ so $I_1 = V_1/R_2 – V_2/R_2$ ------------------2

Using KCL at node A, we get

$I_1 + I_2 = g_m V_{gs}$ i.e. $I2 = gmVgs – I_1$ -------------------3

Using equations 1, 2 and 3, we get

$I_2 = (g_m/(1+g_mR_1) - 1/R_2)\ V_1 + (1/R_2)\ V2$

So

$y_{11} = 1/R_2 \qquad y_{12} = -1/R_2$

$y_{21} = (g_m/(1+g_mR_1) - 1/R_2) \qquad y_{22} = 1/R_2$

Applying these values for S-parameters in terms of y-parameters, with some algebraic manipulations as

$S_{11} = ((1- y_{11}Z_0)(1+ y_{22}Z_0) + y_{12}y_{21}Z_0^2) / \Delta$
$S_{12} = -2y_{12}Z_0 / \Delta$
$S_{21} = -2y_{21}Z_0 / \Delta$
$S_{22} = (1+ y_{11}Z_0)(1- y_{22}Z_0) + y_{12}y_{21}Z_0^2) / \Delta$

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

$S_{11} = S_{22} = 1/D\ [1-(g_mZ_0^2 / R_2\ (1+g_mR_1))]$
$S_{21} = 1/D\ [-2g_mZ_0 / (1+g_mR_1) + 2Z_0 / R_2]$
$S_{12} = 2Z_0 / DR_2$

Where

$D = 1 + 2Z_0 / R_2 + g_mZ_0^2 / R_2\ (1+g_mR_1)$

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

$g_mZ_0^2 / R_2(1+g_mR_1) = 1$

Or

$R_1 = (Z_0^2 / R_2) - (1/g_m)$

So
$S_{21} = (Z_0 - R_2) / Z_0$

Therefore, R_1 and R_2 become
$R_1 = (Z_0^2 / R_2) - (1/g_m)$

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

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 $R_1R_2 = Z_0^{2}$.

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.

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 'f_0', 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.

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.

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