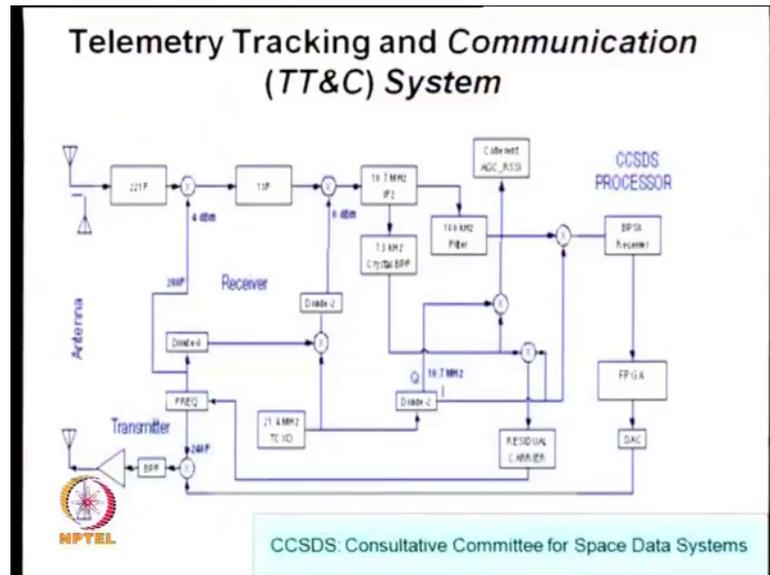**CMOS Analog VLSI Design**
Prof. A N Chandorkar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture - 02
**Introduction to CMOS Analog VLSI Design**

(Refer Slide Time: 00:19)

There are another systems which many of the broadband or communication people use which is called telemetry tracking and communications. If your multi channel data coming in and your multiple receivers, multiple transmitters; so if you see a system which is shown here which need not be actually understood fully just to show you that there is a committee which says consultative committee for space data system, which decides much of they are like a FCC standard decide for communication, the digital part with mixed signal is decided by so called CCSDS people.

So, based on this you can see there are many divided by two or something, but there are some kind of a mixers, there are I have down means that means there is will amplifiers and these are filters. So obviously, if you look at these systems, one of the problem one see since the data is coming at different clock rates and the system has to go through a single receiver parse, in that case they have to be synchronized with a clock. The data may be coming at any other clock, but they have to be synchronized.

(Refer Slide Time: 01:25)
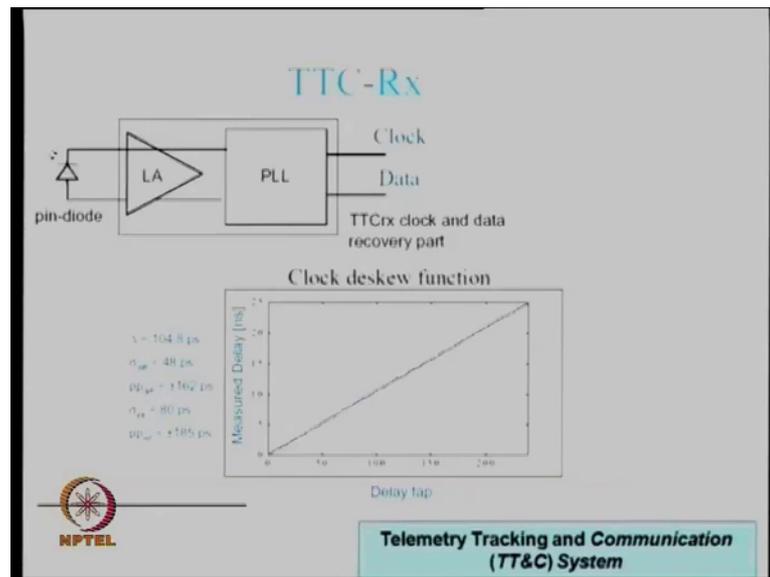
So there is a, what is called TTC-Rx for a receiver. So, basically if you see a recovery data for that for a given clock and there is a low noise amplifier followed by PLL, and that will allow to clock all data coming out at a given clock. And there is a skew function which is equivalently called jitter so you can minimize detail by finding how much time delay one should use. The basic idea there is you actually delay each channel by a given say point one nanosecond and then pick up the data serially, so that everyone is synchronized with one clock cycles. And this requires at least two of the most famous analog blocks, they low noise amplifier and the PLL.

RF is search the independent area, but since it is method of design is almost same as what we do in the case of analog. So, RF CMOS is also considered as analog CMOS. The problem right now is the cost since the cost of a chip mixed signal chip is decided by the microprocessor people or the digital hardware people since the microprocessors very cheap. So, is the memories are downright chips a 256 MB dram may be sold in few dollars or few rupees now, and because of that the technology being so advanced, people found out that bipolar technology though has advanced compared to what I did in 70s and now what people are doing in CMOS still much costlier, but I repeatedly telling you why bipolarizing I am talking.

If you are only looking for analog market bipolar or BICMOS or BiMOS technologies are still the ideal technologies as for as performance schools, but they really very few

independent analog blocks like op amps or something whereas, most of them will be mixed signal and in that case the CMOS will rule. And if CMOS is to rule which is going to say eleven nanometer down now as a new technology node, we are already working on 16 some chips have come, 22 is already marketed and eleven seven may be 0, I do not know So, if that scale down comes, so moves law.

So, the cost will keep on going down simply because the number of components you can put on the chip will be so high, digitally governed market. So, the problem started with RF is, that you have to compute with those people or you have to compute with that technology which is not so very good for RF. Now if you see all the submicron devices all of them are looking for low power, the word itself suggests RF which has a power amplifier built in there you will see some name the word itself is power and then we say like last year one of your senior colleague or dual degree I asked him to design a low power, power amplifier to the first answer he said what are you talking I say that is the fun the power delivered is called power amplifier, but power consumed by the device and the circuit is essentially the power lost.

So, I am looking for low power amplifier. So, I may require a 10 dm to 10 ddm power outputs, but I may require much less power dissipation in my chip. So, that is the challenge right no one is facing, that you are working on a technology which is going for low power and low power, but RF does not want that. I mean if CMOS can do it, it will and that is what is going on. So if you there will be like or we do not like CMOS going to stick.
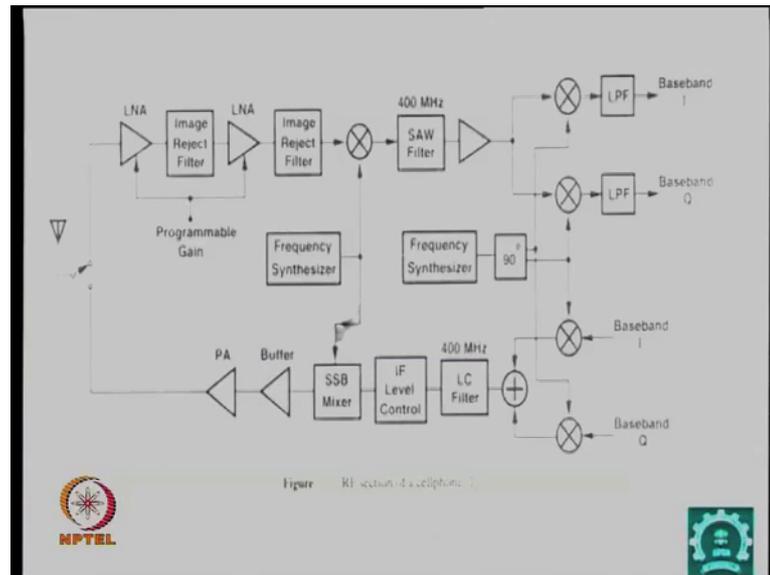
Here is the typical mobile phone architecture, this is their antenna this part is receiver part this part is the transmitter part. If you see there is a filters image reject filter essentially it occurs because of the way you actually receive the signal and pass through a amplifier, there is a band which will reflect by Fourier transform. So, you will see a image somewhere else and if that image comes closer, it acts as a noise I mean reflects.

So, you need extremely low noise amplifier which is shown here, followed by a filter which will remove those images, followed by mixer another filter for lower frequency which is called baseband 400 megahertz or sometimes 200 megahertz basements amplifiers. And once and then again you have 4 because you have you work normally unquadratures, you need 90 degree offs. So, this is baseband 1 and I and Q and this is the two mixers to pass low pass filters.

Similarly for the transmitter side, you can see if there are filters RF level controllers, single sideband mixers, buffers, power amplifiers and there is of course, frequency synthesizes which are like PLS. So, if you look at the typical RF kind of part in the mobile this is typically what is the mobile part. Once you are in a baseband all digital signal processing will start and you will have 8 to d converters and then everything digital. So, the major why we wanted to actually put all this if down, because otherwise the requirement for conversion of ADC are using ADC will be huge capacitors.

One of the important thing of VLSI is the area. We are looking for as small an area for the circuit as much as possible. So, that more and more chips can be created from the same silicon area. So, because of that one has to see here that majority part processing will be digital and mostly now as I say below 45 and this so called RF part has to work on product, which is the biggest challenge all analog RF people are facing. If you allow me to work on 0.25 microns 0.35 microns, I assure you that my performance will be best possible. You whatever any GSM or CDMA or any of the other i-Pads or iPods wants we can give far better performance or if you do on bipolar it is even better, but that it will so he heat. So, much that will have to cool it by putting some. So, maybe fan is required. So, the bulk will go.

So, in some sense bad tools and you want to expected good product.

(Refer Slide Time: 07:57)
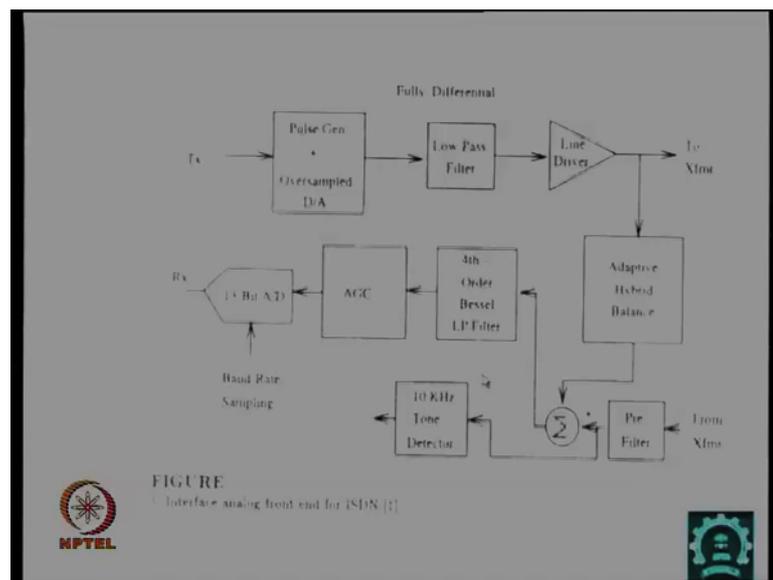
Similarly, if you look at the typical called integrated services for telephones, which has telex fax data everything in one, which is a comparatively higher frequency than normal and, but you can also see there is a over sample due to a pulse generator a low pass filter line driver, which is an amplifier. There is a filter here there is a gain control amplifier a tone detector. So, all of them if you see once you are in xfmr that is you can go for digital, but earlier to that the front end everywhere is in work.

So, our design criteria is, that you should be able to interface digital part and achieve the best performance on the analog and RF part that is the challenge which everyone faces.

(Refer Slide Time: 08:46)

Figure   (a) FM transmitter, (b) FM receiver
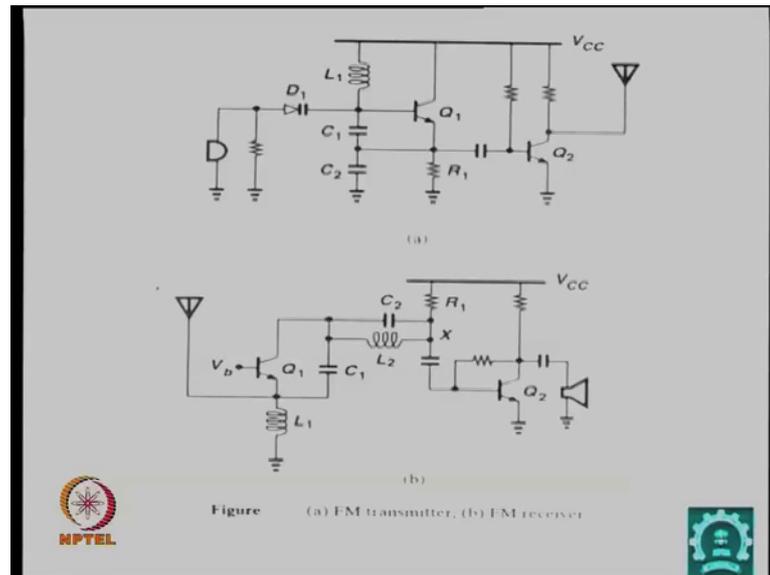
Just to give you a simple circuit of a bipolar RF FM transmitter and FM receivers, I suppose some other course some other people will teach you, but this course may not.
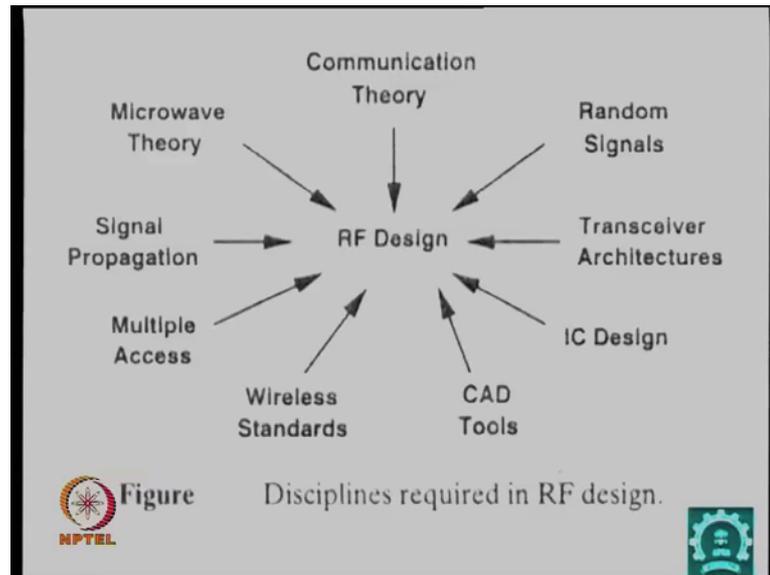
(Refer Slide Time: 08:56)

Modern communication system like model MOBILE communication WLAN, GPS system examples and as I just now said trade-offs are between design and the other parts.

(Refer Slide Time: 09:11)

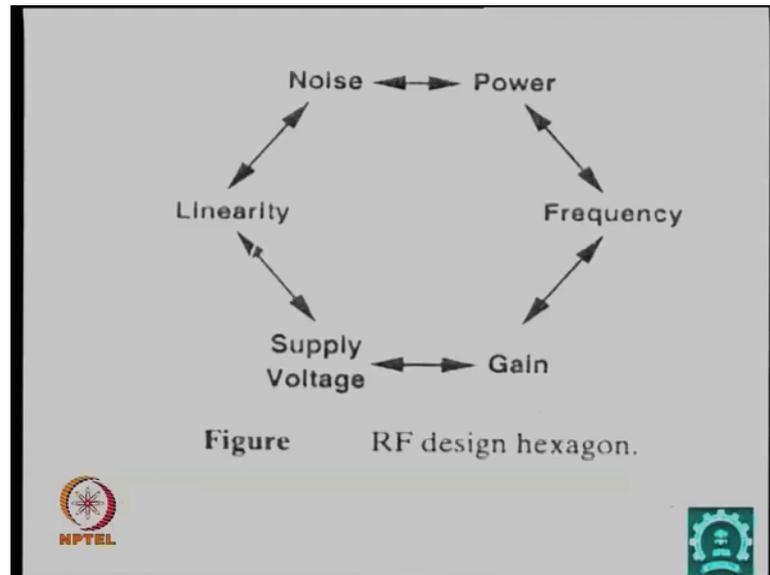Figure   Disciplines required in RF design.

In compared to digital where I do not know whether you are some of you might have already done a digital course or digital design course or maybe now doing it.

The three criteria's we put for a good digital design on the chip, we say it should have a low power it should work as high speed as possible. So, the delay is minimum and third we say it should have a smaller areas. So, it is called triangle, we only optimize between area power and speed. So, this is the triangle and you can see if a given triangle is fixed for a given technology, if you reduce power obviously something else has to be increased by triangle stretching. And, that means we will have to compensate by either by reducing speeds or giving more area, which does not fit into requirements of normal good digital hardware and that is the challenge there.

But in case of RF or analog the design is not only three cornered, it say multi corner discipline for example, a typical design requires lot of theory of communication, you may get random signals, you may have different transceiver architectures, homodyne heterodynes you are required to do a good IC design all criteria's you have to fit in you need law of cad tools you need wireless standards to meet you have multiple access systems LMDS and many other points and you have to know about signal propagation.

(Refer Slide Time: 10:39)

Figure   RF design hexagon.

So, if you see the disciplines required we figure out this is the way. You will have optimize you have gain frequency, power, noise, linearity and supply. There were three in the digital and now you can see at least there are at least fix maybe sometimes seven will came completely.

So, the optimization is not trivial in the case of analog or RF designs and that is the reason why analog becomes more challenging or more requirements from a human intervention is much more in case of analog, than incase if you know as IBM process.

(Refer Slide Time: 11:16)

You know the typical process has been used IBM has a very strong good wireless process CMOS process, which has been used in Bluetooth WLAN set top box transceivers, Mumbai Delhi Chennai of course, compulsorily you should have set up box now hopefully it is good for us, because it is gives so much money if and baseband part of all radios will require all CMOS wireless.

(Refer Slide Time: 11:43)

Challenges for Mixed Signal CMOS …1

- Different performance requirements for analog and digital parts of the chip
- A CMOS Technology, optimized for low power digital requirements, often is worse from the analog performance point of view
- Short Channel Effects
- V_{DD} Scaling Breakdown Voltages
- Transistor mismatch- worsens with scaling
- Nonlinearity of CMOS-based analog circuits
- Substrate coupled noise and Flicker Noise
- Modeling Issues – NQS effects etc. at RF frequencies

So, what are the challenges for CMOS I said it I repeat. The different performance requirement for analog and digital analog requires something else, digital require something else, now you are in a single chip you are fighting each other. CMOS technology is always optimized for low power, but often I gives the worst performance by analog. So, now, again you are fighting for it. The smaller the device you make better is digital performance that is what we are looking for why we are scaling now because we know performance will improve great. The simple reason is the time taken for electron and hole to go from so should drain will be smaller as the channeling goes down, and if the time is smaller obviously speed is higher data can proceed faster.

Whereas, in the case of analog, the short channel effects which are digital is facing is even worst for us, because then everything which I thought as they no noise around, they all will act within noise to my inputs and my worry starts that how do I catch rid get rid of these noise parts. Since we are scaling down V DD for all technologies, we went from 5 volt, 3.3 volt, 2.1 volt, 1.5 volt, 1.2 volt, 1 volt, 0.8 volt. Now we are looking for 0.6

maybe some chips already there on 0.6 and I do not know 0.4 maybe the last I hope. So, because then the noise 1 kt by q is 25 millivolts it is room temperature, 4 kts is the normal thermal noise around. So, 100 millivolt is the noise. So, if you have a 400 millivolt power supply, vt has to be around 0.1 milli 100 millivolt. So, you are in a noise zone ok.

So, one does not knows which device will be switched off or switched on God will tell. So, that cannot happen. So, some way probably 0.4 of course, as whatever I said today it is qualifiable 5 years down, some 10 years ago something I said or 20 years is all true false. So, what I am saying may not be true in future, but maybe I will not be around to compete for you.

The as you scale down there is a transistor mismatch, because the two transistors even close by. One cannot guarantee they are same thresholds same w by ls or same mobilities on if you on a chip, there are so many it is impossible to match everywhere. This is called variability issue some of my students have worked on it, and that is creating a huge design issue because if there is a variability how do design a chip; some part me work sometimes I am prepared may not work sometimes. So, how do you actually figure out that, how do you get the maximum output even if there is a variability.

So, there is an issue which is very important of 2005 onwards, I already said that analog functions only work very small input range, and though I showed you a linear curve there, but if you see at the edges and in reality even that the line which I draw a straight line is only because I wanted to draw it is straight line in real life it is not a straight line it has some finite slopes there, and it changes as you go down in vns though. We assume dv 0 by dv in it is constant you know it is good for us to solve, but in reality nonlinearities exist and if that exists analog functions will give you different gains, different noise if everything different bandwidths and there is an issue involved.

There is another problem which analog is getting, because you are working on a same substrate for analog and digital. Digital switches 1 0 10 1 0 now the substrate bias also keep changing. Any bias change will shift my vt and my vt shift means my everything analog gone. So, I must separate because otherwise I have a issue that anything I own digital is reflected in every analog outputs, there is a noise sitting immediately. Now apart from substrate noise there is they always what we call flicker noise variation I will

come to it later in the course itself which is called one upon f noise. So, lower the frequency you operate higher is the noise.

all said and done after certain frequency when say thermal noise takes over we shall show that, but generally lower frequencies the flicker comes, but lower does not mean it is 0 or something it gives some few hertz, a few kilohertz few now a days even few megahertz. Because cut off is going as much as megahertz because of that the flicker is worrying extremely and as you scale down technologies the variations in mobility, in particular due to interface take variations is very high and because of that the flicker is very very high. So, one of the worry is which all mixed signals people is, you are worried about is the flicker noise.

So, called non quasi static effects, those who are device people have learned devices caused from me hopefully, we keep telling all the analysis, this is steady state or thermal equilibrium. In real life there is nothing called steady state is a non quasi states and since this is non quasi it is states, there are huge problems in modeling and if you do not correctly model at those RF frequencies of mega giga hertz and about, you have more problems in design because what you thought correct is not at all correct and then the design will show you even more problem for it is own, and at then the chip will never work to with respect you are looking I am a not even work. So, that is the major worry of a designer in mixed signal area.

(Refer Slide Time: 17:22)

Challenges for Mixed Signal CMOS …2

- Digital Design continues to benefit from CAD-tool advances

- Analog circuit design still remains a hand-crafted art.
  - Larger percentage of the die area analog circuits occupy
  - Design time

- Cost of mixed-signal chips. The analog part costs approximately two-and-half times to do in 0.18-micron as it did in 0.35-micron (Source Cypress MicroSystems) because it doesn't shrink as much as digital. So if the analog is a significant part of the chip area, one is paying two-and-a-half times as much for that part of the chip.

Digital design so many cad tools, synopsis, cadence, mentor graphic you name there are strong cad tool companies which have provided tools to the as low a technology as a sixteen nanometer tools. In the case of analog there are no such easy tools available, each chip is the different requirements and difference issues come. So, one does not have enough cad tools even in 2012, that you can use those tools. Some tools of digital can be transformed on analog like cadence layout tools yes you may use them here, but cadence have the problem that unless you use a analog layouts areas, what it shows that two lines cannot be separated by certain there is a what is called design rules. These may be very stringent for digital, but analog we do not need those stringent, I can actually separate anything because my area is enough for me. But I will be forced to do that because otherwise that tool will shout and will not allow you to put a layout also. So, they need to be modified for analog function performances.

The problem with all this is that design time is very high in analog compa, per unit area maybe total it may not be as high, but per unit area design time it is much higher in analog then indicative. The layouts are what almost when we say handcrafted, handcraft means by as if you are drawing by hand, rules will give line drawings and all that, but we will have to decide should I put it here or should I put it there. So, decision is mostly yours and not tools. Digital you say I want a and gate it will replicate without you asking it also, it will show you layout for that, because there the library which actually stores most of it such facilities are not available for any analog blocks, which we are trying that is our ultimate aim people say IP creation. Someone other day as IP stand for intellectual property fire designed something (Refer Time: 19:23) and tested that belongs to me and I can sell that technology or that block as an IP to anyone who wants to use that ok.

So, one of the major activity in analog right now is IP creations. So, you create some hundreds and thousands of IPs someone will buy hope and then use it for you and give a some money as well. The analog part costs approximately 2 and a half times that of digital for example, 0.18 micron the cost is two and half times 0.35. So, if you go to 45 you can think of it how much cost I am unnecessarily putting on I know the performance is much better at 0.35. I am scaling down and pushing myself to put more money on it for no good reason I am getting worse performance being higher ok.

You are point most of the analog gm part may be decided by transconductance is proportional to links or root links. So, larger the length of the channel larger will be gms,

in that correct that is our major criteria gm gm should be as high as possible gain gm r gmr 0. So, if I want higher gms I should have a longer length. In digital I will prefer to have shorter link as much as possible to improve the speed performance. So, in some sense I know my 0.35 will be better, but I am working on 0.45 or 0.045 below and now I am asking that performance be as good as what you could have given in 0.35. So, that is what is the major issue ok.

I will come to it anyway that is the course why analog I already said, and you pay the worse is getting worse results and you pay higher universally proportion this is the typical issue I have silicon on insulator substrate.

(Refer Slide Time: 21:14)
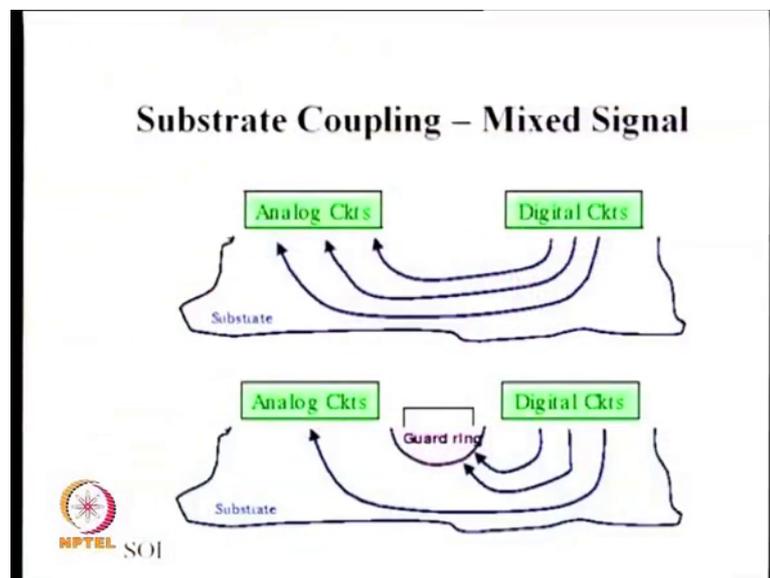
You can see the two parts which are shown here, one is digital block and analog block and through substrate there is a connection it is called substrate couples. Now some other additional hardware or additional processing has to be done which is called guard ring technology some guard rings can be pillar coins. So, we have to put pillars down as much as below. So, huge cost on that, but if you do that digital could be possibly separated from analog to some extent and therefore, the noise coupling may be smaller this technology is costlier. As soon as you go on silicon substrate insulators the technologies at least four times costlier than normal silicon bulk CMOS.

(Refer Slide Time: 21:59)
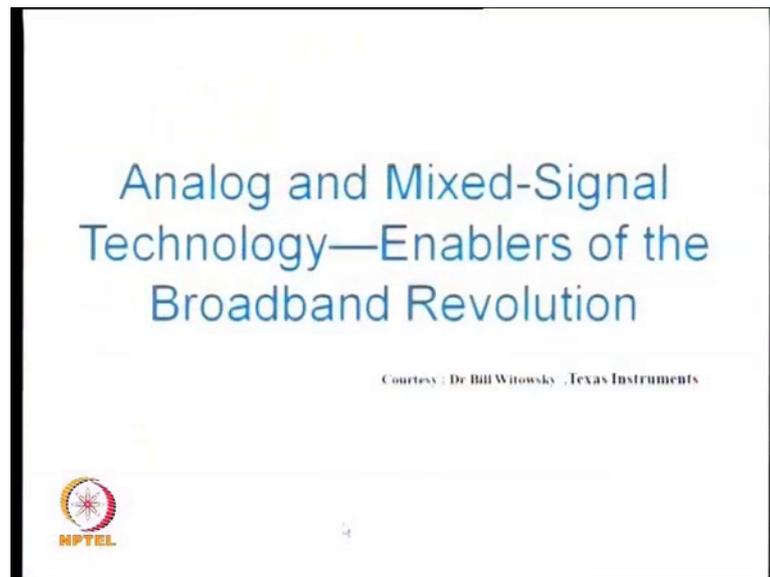
So, cost and you are just quick photographs this is taken from Texas Instruments use it Texas senior fellow of Texas Bill Witowsky. We intend to we have called him some years ago and that is he stock which is being copied here for you.

(Refer Slide Time: 22:16)
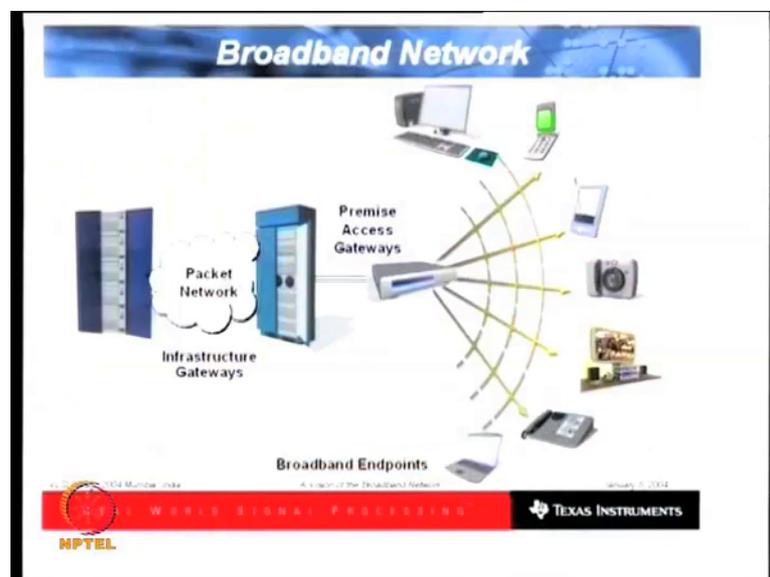
But now the major activity in the RF area is broadband, which is network shown here there is a gateway packet network transmissions, then there is a premier access gateways and so many equipments can be connected laptop video camera i-Pads iPods mobiles and desktops all are connected through the broadband.

(Refer Slide Time: 22:39)
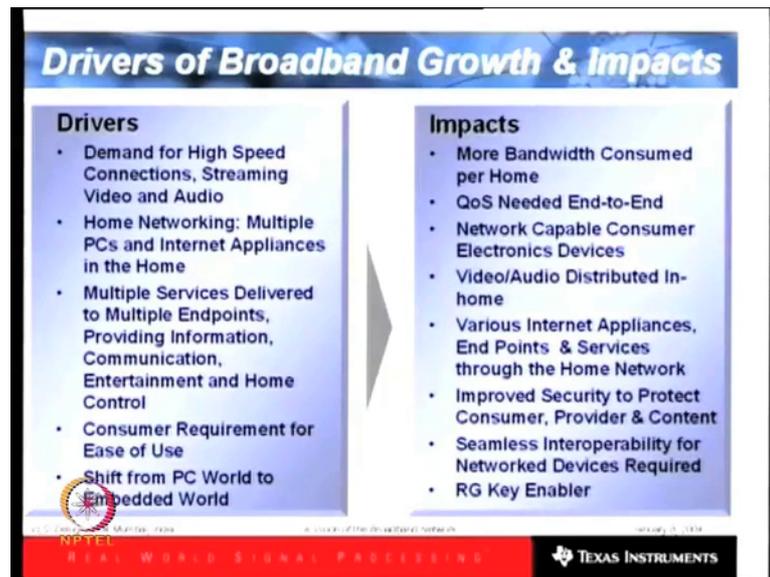
There are drivers or broadband why so much looking, because internet is becoming part of your life and if you want to have video streaming audio of course, is not that difficult. But if you have a jpeg going on it then you have too many standards on mpeg jpeg together and you need huge hardware increments.

So, that is why broadband is very important for most cases. I think these are available mostly you know about the major worry is what we call quality of service all communication people must be happy I am talking they are lying language; one of the major worry in all transmissions is quality of service how services are provided to you. When you reach home from home to your whatever called hub, you go on which fiber you go on fiber or you on wireless or you on copper all these may decide quality of service ok.

(Refer Slide Time: 23:33)
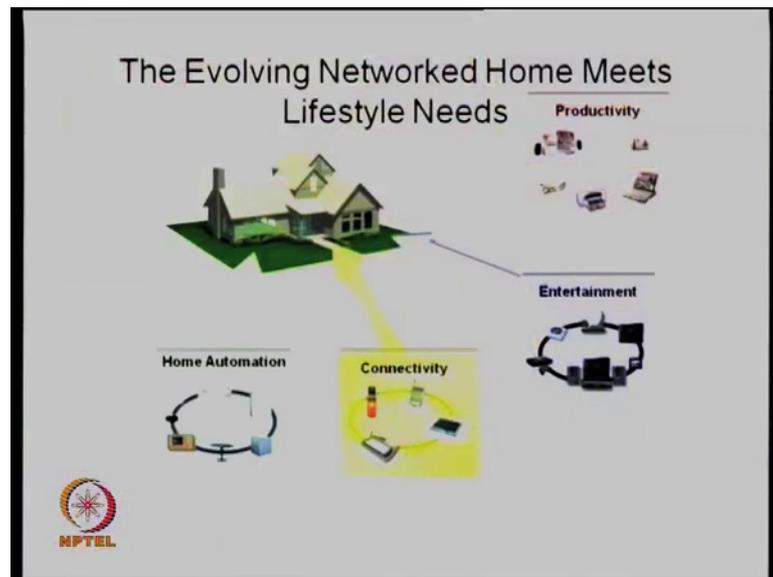
For example the evolving network home meets lifestyle because you are so much busy with working outside. So, you want almost everything automated home automation including washing machine fridge. So, from a distance you should say switch of the machine or switch on machine rice cooker may start at 12.45 one flow that 1 can do that. You need connectivity for all mobiles as well as pads, i-Pads and whatnot you need to have all kinds of instruments which entertains you including television and other through dish TV otherwise and you may work it on a system in which some kind of productivity is required, you have printer or everything exists inside a room or in the building.

(Refer Slide Time: 24:17)
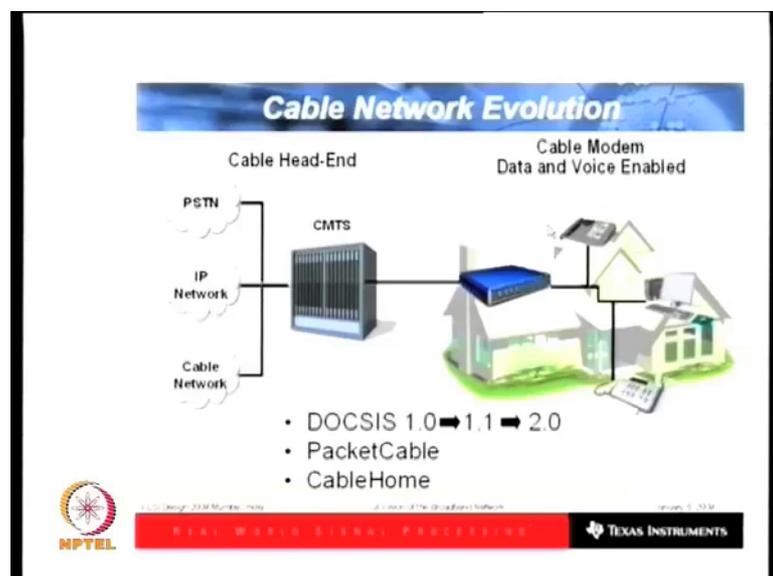
This is what the cable network works most of you have a cables. So, you need a cable modem so that all four services can be given from the same cable.

We worked on 5 years on DOCSIS standard for cable modem, but finally, that ship did not come through after lot of money we spent. But just to idea that cable probably is one of the best because it has the highest bandwidths and you anywhere you see your TV channel on that, you can receive all your data you can receive all your videos you can do everything on the cable itself you need a modem for that. So, right now one is not so much cable modems are popular because mostly satellite direct home is what people are looking into, but the best quality of service can be given through a cable these are all video equipments.

(Refer Slide Time: 25:11)
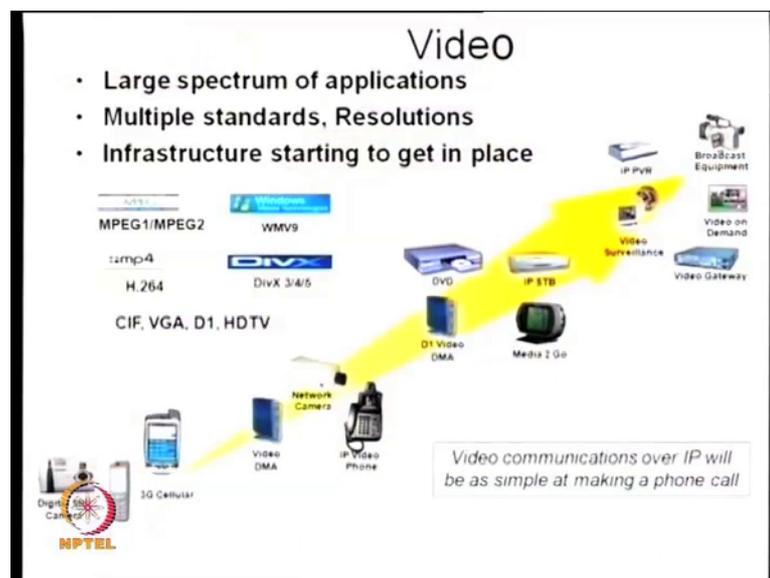
Which requires lot of skills and many IPs can be created for variety of blocks shown here and you can see from a digital still camera, we are looking into broadcast equipment IP VP or video surveillance this is also one area which is very important these days.

Everyone wants to know; what others are doing what he is doing is not interested what others are doing that is the surveillance ok.

(Refer Slide Time: 25:36)

This is the link which is available on fiber, then copper on single fiber, multimode fibers where this wavelength division multiplexing is the standard optical signal processing methods. So, for these also which may run as 100 gigabits per second kind of frequencies I mean data rates. So, one is looking into variety of structures giga gigabits internet. So, net and many of them which are required all of them will be requiring some design which requires analog RF or a particularly broadband.

(Refer Slide Time: 26:10)

As I say broadband is fueled by consumer demand, everyone wants a broadband home broadband access is evolving very high speeds, always on internet to the connected home you want of course, all of us I am no exception. Of course, you some of you are exceptions I know; if I send the mail you send reply after 7 days, either by design or by not looking your own mailbox, either way. Particularly tas you know if they are not done the job they keep mum, because then you know if they reply they will have to say have not done.

So, they as if the mail has gone somewhere into the black hole; everyone knows that if the mail has not bounced, I know it has reached you can never say that it has not reached. But he said now I did not receive some [FL] human hand, this is good for. All of us you know mobile has given this advantage and I am standing here and I say I am in Delhi, go on those, but once that 4G 3G starts if the video comes on it actually background will be seen you know and you cannot say I am in Delhi you know you are very much in Mumbai next 5 minutes away from the place, but you are telling I am in Delhi, I cannot meet you this advantage probably may go soon ok.

So, probably one is we are looking for what we called system on chip, many activities of a analog digital or can be put on a single area called system on chip everything together individual chips, but put on silicon this is like at the PCB becoming silicon ok so, that is the issue see.

(Refer Slide Time: 27:48)
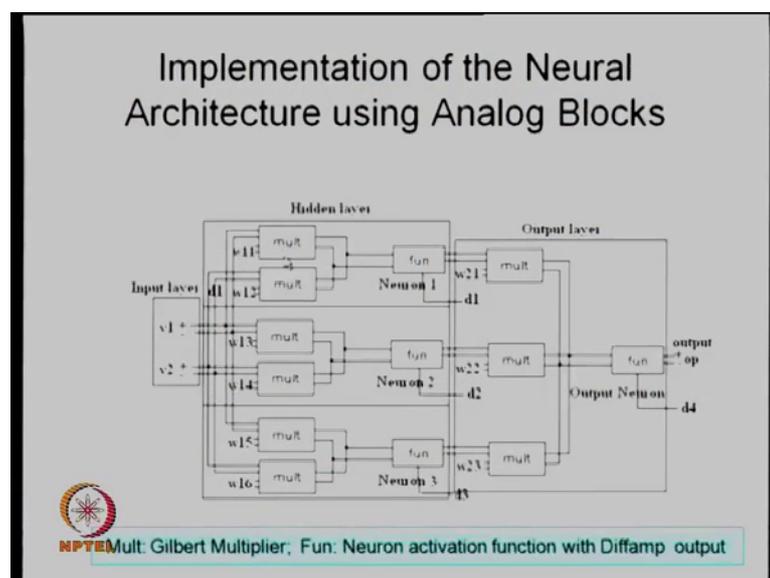
If you see a typical neural architecture, there are some can see some of the inputs of them I have shown you, these are multipliers then there is a output you required which is called neural activation function, which is a actually which need differential outputs ok.

So, diffamp; so even in this smallest part of a neural network which I neural process I showed, there are at least 11 only two layers I shown you, there are 11 multipliers and at least 6 the diffamp required. So, even for any kind of processing the digital part is fine, but analog is very very important neural of course, as I say mostly analog.

(Refer Slide Time: 28:28)
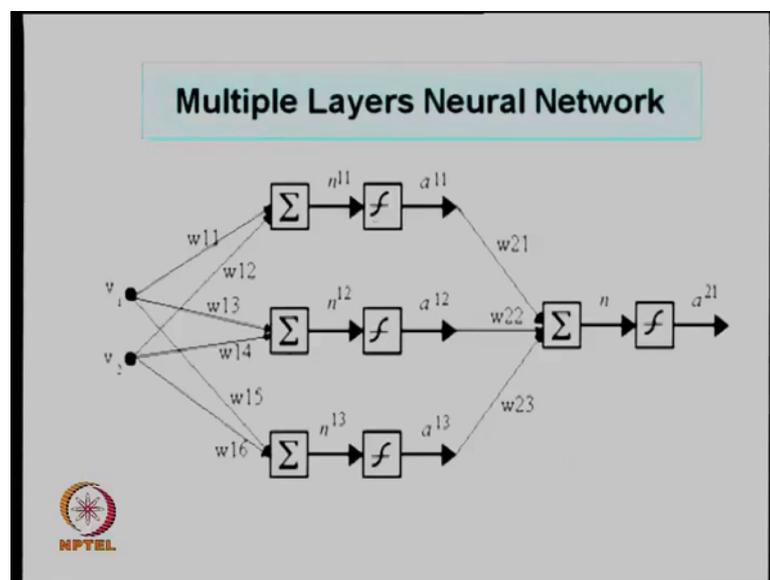
This is how you can see there are multipliers adders and neurons, weight functions means actually multiply synopsis this is the neural network, some other it is some other in time.

(Refer Slide Time: 28:40)
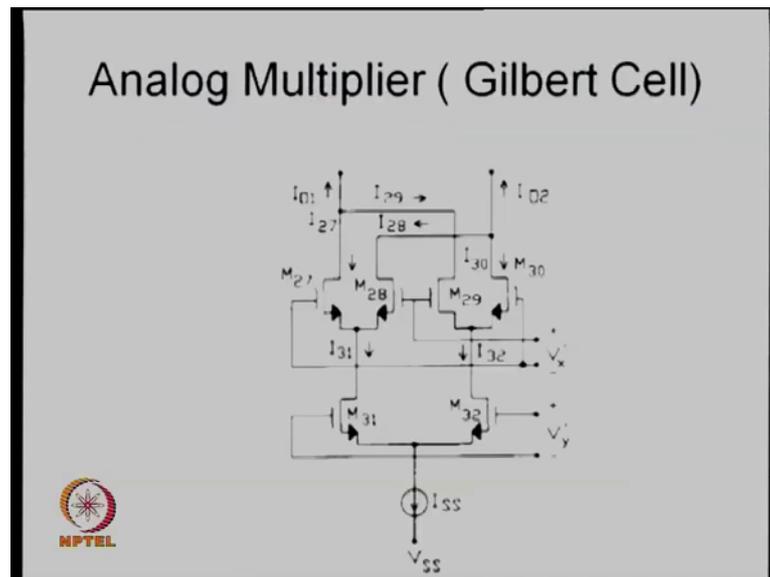
Typical analog multiplier is shown here, this is very famous circuit called Gilbert Cell it is a two diffamp cell or other two the two diffamp put together looking like three diffamp, this is the analog multiplier. This is generally current multiplier and that is the strength of it ok.

(Refer Slide Time: 28:59)
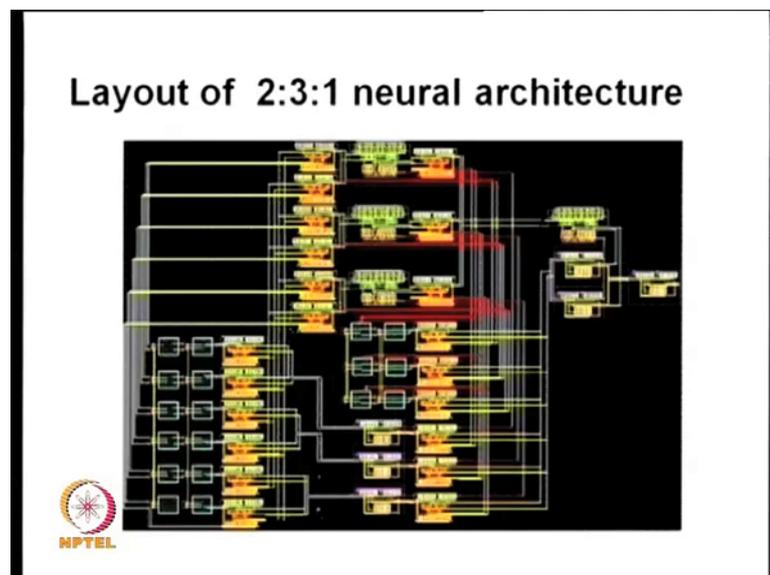
This is the typical actual architecture of a 2-3 one neural the network architecture prefer a processor, which was designed by one of my student in feedback maybe 1994 or 95 therefore, not referred because this is ours ok.
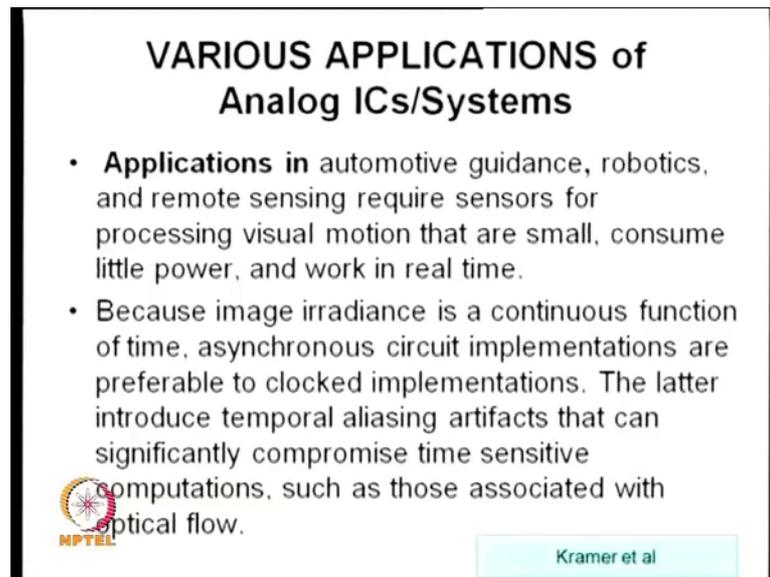
VARIOUS APPLICATIONS of Analog ICs/Systems

- **Applications in** automotive guidance, robotics, and remote sensing require sensors for processing visual motion that are small, consume little power, and work in real time.
- Because image irradiance is a continuous function of time, asynchronous circuit implementations are preferable to clocked implementations. The latter introduce temporal aliasing artifacts that can significantly compromise time sensitive computations, such as those associated with optical flow.

Kramer et al

So, where is the ICs analog ICs or systems going, mostly now they are going into automotive guidance, robotics, remote sensing and all of them require sensors. For example, you need a sensor for visual motion, which are very small consume little power work in real time like car is going on you want to see you some collision this or you want to check your tire pressure or you want to check something or you are connected to GPS.

Now, all this will be requiring that the energy optical energy, which you receive a radiance is very very smaller that energy is very smaller and the processing has to be much more accurate. So, the worries starts that how do you make processors, which are a different time frame it will come and it is not a fixed time that every nanosecond I can pick up a data, it may come in Pico second it may come nanosecond may come in milliseconds.

So, the processor has to have way of knowing which data is coming one. So, mostly what we do is called asynchronous designs, which is not clock to a given single, but at that to processing we will require synchronizations. Whenever you do this though then digital of course, everyone signal processing everyone then there is a until artifacts we will be seen. So, you require all of DSP kind of approaches to improve that.

(Refer Slide Time: 30:42)
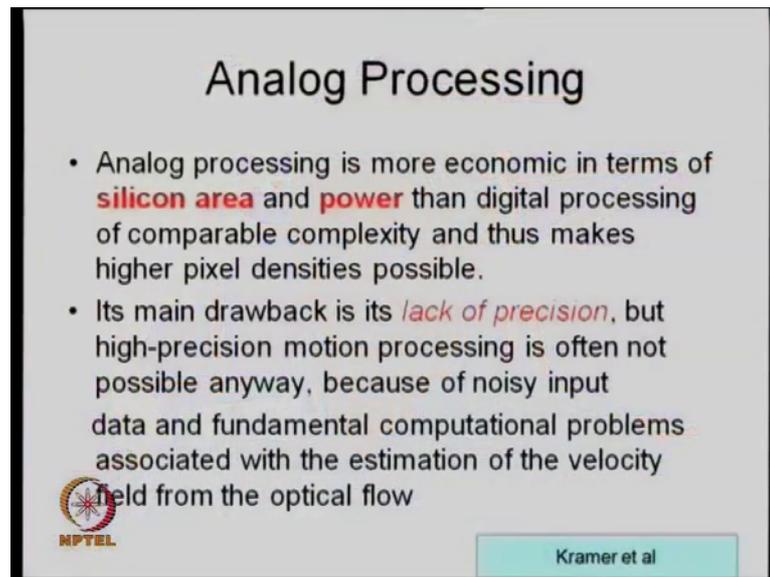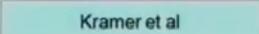
Now, this is what everyone has so far so many years including us have said that, analog is costlier. So, here is one slide which I took from after great difficulty figured out, that analog processing is actually economic compared to digital. So, how is the comparison? Here is the one the comparison goes that if you see them for the same complexity analog and same compressed digital, analog is cheaper. But what you do is you compare it to say Intel Pentium four or ethylene or Hetrion one kind of this with a RF amplifier oh oh how much it is same.

So, the comparison is not correct. So, therefore, they say that analog is very costly or digital RF is very costly. In fact, as I say per block design if you see analog will be cheaper. Because you know then that is how we can make a lot of pixel based system which can be addressed very small I mean large number of pixels can you put a smaller area can I address very easily actually. The problem with all analog processing is, it has a lack of precision digital you do not have real precision you (Refer Time: 31:52) a 0 1 [FL].

So, the problem is lack of precision and, but many of these for example, collision if you are have a collision detector, you do not want the card should be within one nanometer to know whether it will hit you analog. Even if it is a few centimeters I know I am hitting there or not. So, mini systems really do not require that precision either. So, why are we fighting on cos not precise, it is enough precise as far as their application goals. So, there

are issues why I am showing all this all designers should get rid of this fact, that what is the best design there is nothing called best design a design which works for a given application in a given money which someone buys is the best. If that does not mean either of the criteria even if it has the best of specs no one buys it. So, what for it ok.

So, we design is as good as who pays and whether he is satisfied with the data, output I am getting if both are satisfied thank you very much. So, do not work on the best kind of designs there is nothing called best. So, best for an application for a person or a for an applica user; if that meets whatever money it is so what? If some specs is fantastic like is space or someone ask you, you say pay 10 million dollar for this chip I mean he only one 10 chips he wants I have to design what specs also horrible, I will charge you.

So, that is the way design goes do not get into this idea that of course, in exams we keep asking optimization we you know this is academy. In industry there is nothing academy this you take from me now. There is a 0 academics in industry many of these systems will require sensors which are motion sensors as required.

(Refer Slide Time: 33:45)
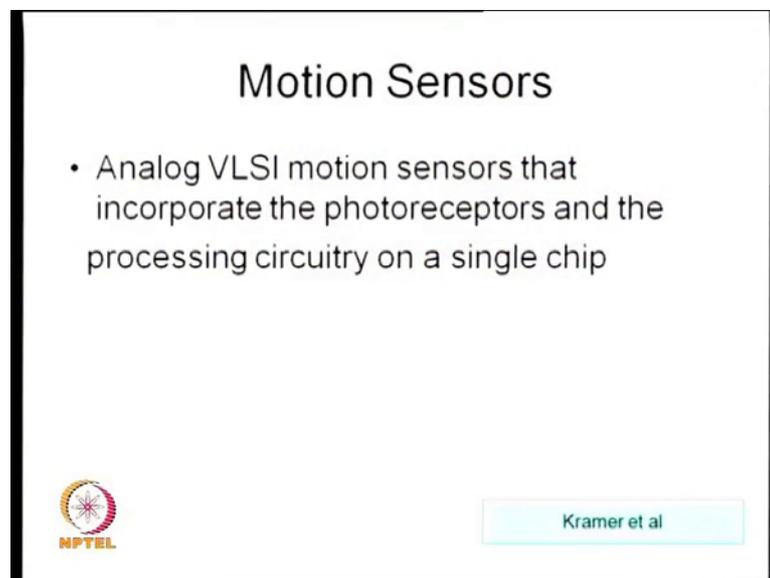
They are actually photo receptors and they have to be processed on chip now, that is why this nanolab probably may help ok.

(Refer Slide Time: 33:54)
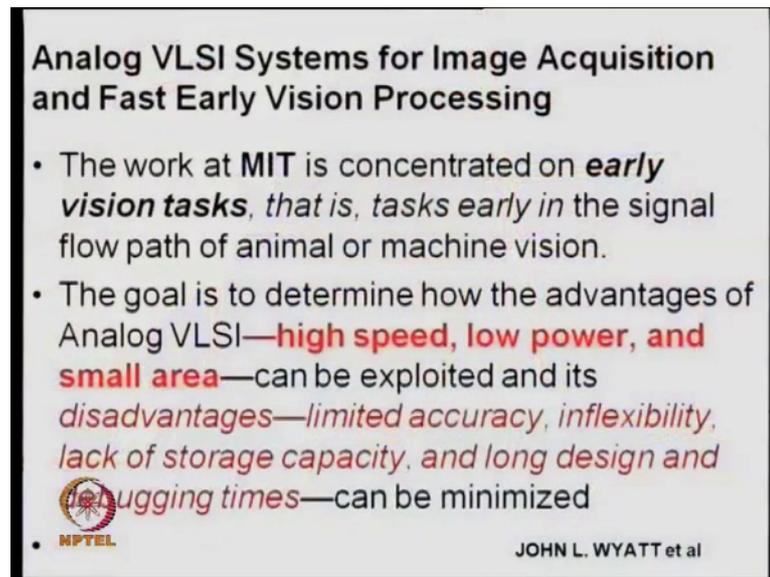
Analog VLSI Systems for Image Acquisition and Fast Early Vision Processing

- The work at **MIT** is concentrated on *early vision tasks*, *that is, tasks early in* the signal flow path of animal or machine vision.
- The goal is to determine how the advantages of Analog VLSI—high speed, low power, and small area—can be exploited and its disadvantages—*limited accuracy, inflexibility, lack of storage capacity, and long design and debugging times*—can be minimized

JOHN L. WYATT et al

Like in the case of MIT I give some university where very famous. For example MIT has been working for last 20 years or fifteen years at least I know my good old friend doctor Chandrakasan, they have been working mostly on vision area including I and everything all kinds of vision products.

Basically, signal for part of animal or machine how to actually vision comes, they are mostly working on bio analog or analog bio whatever it is. The goal is to determined how the advantages of analog will decide which is high speed low power and small area can be exploited. And as I said it has a limited accuracy very inflexible most memories of course, I will show you some memories today if possible. It takes longer to design than normal digital and it takes h hell of a time for debug it whether right or wrong this thing is very difficult. So, if you can minimize that this is a good challenge.

One of the very famous book of seventies or eighties rather than sorry it is come from a Ismail and Faiz which is now I am told available in India, early it was not I have a copy as I said I will not give.

(Refer Slide Time: 35:10)

Mohammed Ismail's Analog VLSI research At Ohio University
Circuits for Communication, RF CMOS, multimedia, Instrumentation, Sensors, Medical, and Automotive Electronics

· *A project completed recently focused on the design of a CCD imager interface CMOS chip with a CDS(Correlated Double Sampling), AGC and A/D converter for Camcorder*
· *Ongoing and near term projects include chip design solutions for multi-standard wireless applications:*
· *The research spans the RF parts(LNAs, Mixers, I-Q generators and buffers), baseband parts including channel select filters, variable gain amplifiers and high speed data converters, and frequency synthesizers parts including design of low phase noise VCOs and PLLs.*

This person is still at Ohio University and they work on the area of communication RF CMOS multimedia instrumentation sensors medical and automotives or I am giving show. So, you also can think these are the areas, in which analog VLSI is useful a project 2010 they completed with the design of a CCD image or interface with CMOS chip, with CDS which is co related double sampling, they also designing AGCs ad converters for the camcorder, they have a near temperatures called chip design solution for multi standard wireless, which is becoming very difficult right now you have CDMA TDMA learn different kinds LNAs different internet connections. So, you need different standards and then you have to design a chip which meets three four standards.

The research spans in RF parts LNAs mixers IQs that is quadrature generations and buffers baseband parts include channel select filters, variable gain amplifiers high speed data converters synthesizers and design of low face VCOs and PLLs.

(Refer Slide Time: 36:18)

A very interesting memory has been of course, this is not from Ismail a new memory has come now, which is called floating gate analog memory. It is new in the sense actually it was known and I was maybe not I was studying after (Refer Time: 36:32) maybe 17th.

Analog was known to us earlier than digital as I said you. So, we knew about this so call an analog memory then, but we could not think of that it will any time come, because in those days the flash was not meet. So, now, we are using the splash digital memory what you call and trying to see can we use the same technique or technology to create what we called analog memories. The basic analog memories are the storage of current of a constant current. So, one current is one bit the other current in other bit. So, I can have a current mirror which has a constant current generator somewhere, which stores that current. So, that is what and we use the same structure as e square prompt structure to do this computing it kind of memories.

(Refer Slide Time: 37:22)

Analog IC Market
A Strategic Overview and Opportunity

Content

- Analog IC market
- Characteristics of analog companies
- Strategic considerations
- Opportunity in analog IC market
- Summary
- Author of this survey :Khanh Le

So, this is a new memory which is probably is going to be used very soon new flash, what is the advantage of current storage over voltage storage anyone? Why all these actually looking for charge storage is not it qcv. So, v is the one which control there is no I in that though we know very much inq are related 2 by ts i, but that t factor was very troublesome now we can manage the t. So, current storage is better much more accurate much more easy to create compare to digital. Because larger the capacitance you create on silicon huge area it picks up. So, we want to reduce that area. So, one possible way of doing, the only problem may come now again we may have to look for current to voltage converters. So, some op amp basic it will be required, because that then we may have a digital voltage data, but these memories may come soon maybe already they are made. So, maybe another few years they will be marketed.

Now, before we quit on this, I must like to tell you many things about analog because you all are analog IC market strategic overview an opportunity. So, I will just go into number of these points market characteristics strategy an opportunity, why opportunity you may like to join. So, what are the IC market drivers as I said? Drivers means those who are pushing analog circuit designs automotive electronics.

(Refer Slide Time: 38:56)

I will said something about it already consumer electronics energy mobility, security and the major right now everyone is looking is health care. Anything you put a buy on that you are 10 levels up.

(Refer Slide Time: 39:08)

So, if you look at the market characteristics for analog, typically the market is decided by the money. So, last four year dollar in billions we are talking about, and it is found that the improvement in analog technology or analog product is proportional to the other

semiconductor technology products. So, it is not that this is one area and that is one area they are correlated if that does not go up this also does not go up.

So, it is very strong correlation functions, typically we have found that 10 percent growth is seen in analog, this is cumulative aggregates which I am showing here average to this. Growth rate is from 2010 to 16, say 42 billion dollars in 2010 which was 30 percent from the growth in 2009. In 2010 became 42.5 billion dollars and by expect that in 2016 it will be 74 billion dollars the total silicon market is as of now is 800 billion dollars ok.

So, we are not at least 10 percent to 12 percent is something which we are actually working out. There are 5 famous companies in analog some of them and in India maybe all of them are in India also. So, for example, very interesting if I rank them of course, this is not given, but the I have just took an different data and put it in the form to for you to see. Texas instrument is number one analog company in the world which has the 6190 million dollar business in 2010 which has the market share of 14.6 percent.

(Refer Slide Time: 40:51)

The ST which is both based on France Italy and US and also other European countries, it is rank two they are more famous for their memories and other wireless products, but I am comparing analog part of the.

There are 4291 million dollars which is 10 percent. Infineon which has now become part of it as become Intel mobile, but reminder part of Infineon, which were earlier Siemens

semiconductors. Infineon is number three in analog market 3328 million dollars business in 10 and it is around 8 percent share. Analog devices they also worked on a lot of DSP products, but their analog part is they are rank forth around 2500 million dollar business 6 percent roughly they are share and the one is very smaller company compared to these four is maxim, which is fifth which has around 2000 million dollars which is only 5 percent on the business they do, but they do very niche business the others make 24000 millions or 22000 million dollars which is 56 percent, but if you see the first 5 add the 43 percent market share is really going to 5 companies, that remember 100 there are 107 companies totally who actually work on analog.

So, the 56 percent with them and 5 sharing around 42 percent, and if you take it 10 now it will be 60 percent will be with them. There are few bigger company I did not list linear and others, but some other time there are segments, there are two segments in digital same is two segments in analog now very strong segments; one is called application specific the other is called general purpose like op amp is a general purpose [FL] op amp.

(Refer Slide Time: 42:45)

So, we say there are analog ICs that perform specific function like timing control RF transceivers, touch sensors led drivers led quotars display drivers and may have general purpose like multiple application like amplifier DAC ADC comparators latches all these sense amplifiers all these are essentially general purpose they do not go for a system. So, if you look at their market in 2011, the application specific market is 26.3 billion dollars

a question is many time I am asked why I talked about billion. Firstly, I am copying from someone; they talking dollars.

Secondly we do not have even 1 percent of this business. So, showing you some 22.6 [FL] business very odd then say why do I join that company [FL] attraction [FL] 26 billion. The general purpose market is 18.8 billion, the main segment in 2016 the aic market will be 40 billion and the general purpose market v will be 32 typically 74 billion dollars market will be another three to 4 years of time ok.

(Refer Slide Time: 43:56)

So, what is the environment for them analog IC companies compete through what are those skills they require they special products design skills. Each company has people who are expertise in one specific area they can do this best. So, they will actually use those skills then companies also compute on breadth of. The how many products different kinds I create that will decide my company success. How much I able to distribute and how good is network that company has will decide which will be 1 or 2 or 3 and of course, finally, if not the; it is not the last in the most important how much pricing you do for your products that decide the environment for any company.

So, larger companies go by this, but if you look at the smaller companies I have listed of course, these are not all from Canley some are my own I added there itself. So, there is a small company in Korea Asial let trend the only work on power management unit that is they are only area they do not work on any other chip this stick they work on power

management and led drivers Niko and power analog, Micro they work only on high voltage 20 volt 50 volt power devices of power device based analog circuits. GMT works on audios which is power management, Taiwan semiconductor works on discrete voltage regulators op amps, Sitronix works only on LCD drivers silicon Mitus for only environment.

So, there are many others I will just did not list all of them. So, smaller companies actually choose a product or two and stick to that, then they can create some niche market. Whereas, bigger companies have other idea, they say larger the breadth more you can make money. So, that is the difference between the two kinds of market; everyone survives do not worry why I said you a few lines then you will see it.

(Refer Slide Time: 45:51)

Audio video clock timing data conversion for example, simple I give one example; in 2010 ADC DAC market has 3.8 billion. Only on ADC DAC or for example, similarly an power management block the budget was I mean sell was almost 10 million dollars.

So, certain areas are much more required in the market, some areas are not required, but how to create breadth and you have to create different. As I say if you divide the industry by application, there is a automotive communication computing storage consumer industrial medical are the areas which are called segments.

(Refer Slide Time: 46:30)

And for example, Taxes has 30000 products that is an instrument, linear has 7500 products, national semiconductors is 12000 products and maxim has 6500 products; there are major analog companies.

(Refer Slide Time: 46:49)

I will show you I did not add that word latter, but that interesting part. Then what are the technologies people are working at you know very difference different technologies have been tried for different applications, Bipolars many companies are working even now for amplifiers, RF blocks regulators power management and some discretes. BICMOS or

BiMOS they are working for RF amplifiers power management; for power specific large power we work on DMOS or VMOS or sometimes DMOS drain extended mos for high voltage applications, but do not think high voltage means really 100 or something, 50 is very high compared to 0.8 very high voltage; high voltage is also now much higher than 0.6 or 0.8.

CMOS everything wherever you there and there are technologies are very recent array which is silicon germanium, it is because Intel has popularized it for their own microprocessors. Now, it has gone for any every other area, RF is very strong on silicon germanium and there are companies, which are working on silicon mixture or silicon carbide in silicon germanium call ceg carbide technologies, which is mostly used for ultra wideband 22 gigahertz in above, which is a very great challenge right now.

(Refer Slide Time: 48:21)

Why we are looking for higher frequency larger is the bandwidth each industry segment requires specific analog mix signal technologies. For example, consumer requires the screen, led drivers, display drivers, near field communication what is near field communication.

So, these are essentially required for consumers which we want to connect your printer you want to connect with so many sitting one common printer through Bluetooth I or can be ir Bluetooth. You for a video, audio, codecs these are consumers industrial, led lighting, energy monitoring. These are same things in different format I am showing you.

Automobiles you need sensors, ADCs, line drivers, audio codecs for computers todays you need HDMI, SATA, thunderbolt did you see some hardware and softwares methods and communication: gigabits, you know gig b as it is called gigabits gig b.

(Refer Slide Time: 49:19)
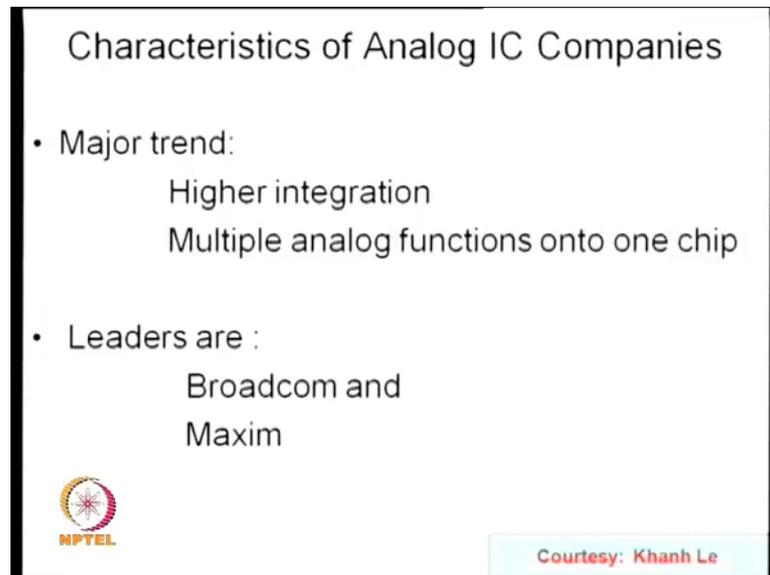
So, 10 gb 10 g 40 g is what people are now working at internet. Larger the bandwidth to provide longer the distance your net can actually get connected without fading. So, major trend in IC companies is higher integration, multiple analog function on a single chip and of course, the two people who are actually made hell of a money in last 2 years, people believe that QUALCOMM has more made more money, but QUALCOMM has different products analog to Broadcom. Right now the leaders in pure analog RF related products, Broadcom is one and maybe maxim is just makes to it [FL] company in this ok.

(Refer Slide Time: 50:05)

So, what is the characteristics of analog companies are? Very high profitable they should be they should be large operating margins with them for example, linear has 52 percent operating margins, another device is 30 percent maxim 26 percent and the gross margin for example, TI is 53 percent gross margins, national semiconductor 68.3, linear as 77 percent gross margin. There is a very important word in industry which I therefore, wrote fully down. So, that you remember only P you may forget it is called price to earnings ratio.

How much earning you want and how much pricing you will do is a very important decision of a company, and that decides whether the company will survive or will not survive. If you have put very high price to get higher earnings for example, ratio to what you are spent, and many lesser products will be sell. You put very low you may be bankrupt. So, you have to be very very strict on p ratios how much company can afford to sell at what at what earning. They expect because there is something minimum earnings they have to do, this quarter may [FL] loss [FL] quarter [FL] this is very important.

For example linear has 15 percent, ADI is 14 percent maxim. Maxim is very strong people; they actually decide how much earning they should minimum and how much pricing they should do. But there are many niche products and therefore, these survive. This should be resource intensive. And, for example, many larger companies has

advantage they have huge number of application engineers with them for example, Texas instrument NSC maxim has more I think application engineers than designers, because they should bring the business to them and sorry.

(Refer Slide Time: 51:56)

Characteristics of Analog IC Companies

- Diverse set of products and customers
- Tens of thousand of products and hundred of package types
- Tens of thousand of customers at all volume levels
- Hundreds of distinct applications in each market segments
- Longer product life cycles than many other IC types
- Very low ASP ($0.48) but very high volumes (88 Bu)
- Most large companies own fabs – esp. TI, NXP, LLTC, MXIM, etc.
  - Own recipes and optimized processes
  - Leverage process R&D across products
  - Depreciated fabs keep cost low

Courtesy: Khanh Le

So, any company which has to survive, they should have diverse set of products and consumer customers, tension thousands of products, hundreds of package types tension thousands of customers of all volume levels, hundreds of distinct application in each market segment, larger product lifecycle than any other IC types, very low a asps profit at the start, but very high volumes. If for example, the very low profits can be as low as half, but this may be half a dollar half a million dollar, but we may produce a company which has 88 million billion dollars they may actually sell over the years.

The most larger companies like TI, NXP, LLTC, MAXIM they do all this the biggest advantage they hold is this own recipes that is own processes they have they have optimized processes for their own products, and they leverage their process r and d across the products. Like Intel does not give it is app to anyone Intel manufactures it is own microprocessors, why? Because if they do so, then only they can leverage that whole process that is better. Otherwise if you give it to someone else, other men will know what you are doing and that is the major fun.

So, all these companies the smaller company has that disadvantage because they cannot afford a fab. So, they will have to go to someone. So, the product [FL] release [FL]. So,

your timing is what crucial they are you makes it that much product, which is someone else will be interested, since [FL] the interested in your product. So, fine you work on it and see to it when they pick you up. You do not you are not interested in the end of your product either, you are just waiting when that company will pick you up that is what is startup businesses ok.

(Refer Slide Time: 53:49)

If you look at strategies and market force for each company, the strategy for maxim is integration innovation and balance, market is, automobile, HD infrastructure, energy mobile, security, healthcare, linear has strategy of broad based supplier quality, market focuses communication, industrial automobile, Zarlink have strategy of network evaluation and healthcare. This company has started basically for health care. So, Zarlink was not there in few 5 years ago; just picked up a figure out that healthcare market [FL]. So, let us enter.

So, they are major product right now is in healthcare. Of course, they work on wireless for healthcare that is their major interest. National strategy broad based supplier of high performance, energy efficient analog and mixed signal.

(Refer Slide Time: 54:41)

Strategic Considerations

- Opportunities
- Growing appetite for analog chips in major industry segments
- Consolidation re-started with TI's acquisition of NSC in April 2011
- Several potential acquisition targets exist in US and elsewhere
- Threats
- Current partners of TI, STMicro, ADI, etc. will block entry or limit playing field

Courtesy: Khanh Le

In most important part which you can see, how much apart strategy something like what are the opportunities what is the growing appetite for analog chips in industry, consolidation re started with the problem you know this is called disruption, what does happen last year. The Texas instruments picked up the one of the largest semiconductor company other than international semiconductor, they just picked it up ok.

Now, they are part of Texas. Texas is a smaller company than NFC, but Texas is the owner of NFC now. Because of that now the analog products their own competitors, they are part of them. So, they just kill the competitor by acquisition of course, they are still other companies. So, they are not under MRTPL act no monopoly. So, they still survive, but that is the way it is. So, there are potential acquisitions are now on target and therefore, there are huge threats to middle level companies. Startup is actually looking for acquisition. So, for them it is great if someone actually picks up.

So, for example, I will just word is all these big people, therefore will not allow anyone else to enter the market because that is the strategy.

(Refer Slide Time: 55:54)

Application-Specific Analog Opportunity

- **Application-specific Analog** sees increasing share in the IC content of DVD, mobile devices, DTV/STB etc.

  Example: A i-Pad either with no 3G or 3 G costs around $ 225/- & $ 260/- in US Market.

  The *Analog share is around $ 55/- (20 to 25 %)*

- **Great Opportunity for Other innovative startups and smaller analog IC companies**

Courtesy: Khanh Le

Just to give an idea a i-Pad, there are two kind as I say operations for example, the application specific some of them; for a i-Pad of three g no three g or three g whichever way you would buy typically to 25 dollars to this is little old price, but available on the net and the analog sharing that is 55 dollars, which means around 20 to 25 percent part of an i-Pad and this is becoming. So, craze to everyone that analog market will grow continue it is show increase.

So, what is the opportunity for you all, is the greater opportunity for other innovative startups and smaller along IC companies.

(Refer Slide Time: 56:34)

So, strategy [FL] what is the difference you can make innovative designs and good analog performance? System friendliness and custom package [FL] package [FL] you should meet their applications. The focus is of course, on cellular wireless transceiver, power amplifiers, power management chargers, supply control, LEDs, Wi-Fi, GPS, Bluetooth near field communication devices, transceivers and controllers.

(Refer Slide Time: 57:04)

31 percent billion dollars discretes may 2010 36. So, 13 percent growth [FL] better to join now [FL].

(Refer Slide Time: 57:14)

Billion wireless product 2014 may becoming or Wi-Fi [FL] 3.8 billion dollars 10 billion dollars [FL] remaining [FL].

(Refer Slide Time: 57:25)

In nut shell large and consolidate analog IC market which is around 42 billion non way become 74 billion soon it is a horizontal market; that means there is no hierarchy. So, everyone is on those different or are different. So, they are on a horizontal plane different segments, they are catering to the asps as low as half a dollar many units, which are very

high volume 88 billion units on me. Therefore, the application specific analog is the most attractive segment for entry by innovative startups.

(Refer Slide Time: 57:59)

Finally what are the key problems one is (Refer Time: 58:02) key issues particularly wireless an analog IC market, you know in between semiconductor market went down very heavily last 2-3 years service now it has come back.

So, since it is tagged with that will analog will also have a nose drive. So, that is very important issue; when analog ices remain viable in future or will they be displaced the all digital, will analog ices remain viable as I say is the market becoming increasingly application specific will multi market device lose their share of market, where is the best opportunity of growth in analog ICs whether it is in power area, signal processing area, interface area, these are the issues one asked to answer.

(Refer Slide Time: 58:49)

Analog Integrated Circuits Market to 2016
Electric Vehicles and Portable Medical
Equipment Segments to be Main Source of
Future Growth

Unstoppable Rise of the Smartphone Will
Drive Analog Integrated Circuit Market

Analog ICs are used in a wide range of
applications including third and forth
generation (3G/4G) radio base stations and
portable device batteries.

However, two things may help you, in 2016 people believe that electrical vehicles and portable medical equipment, actually that segment may grow very fast healthcare and second read one, eye intentionally put read because I think this is the largest growth market rather of now because of the younger population across India and world smartphone every one want like this. Since, you want that smartphone there is an analog 25 percent there may increase even now and if that increases jobs in analog and going to stick from many more years.

I must honestly tell you all companies in India are looking for analog engineers because of this 25 percent front end. This I will show you next time, but I one last slide I must show you which is interesting.

These are the come people who are whom I am acknowledging the Razavis book, on a Razavis personally I talked to him, TI people cadence the number of websites from VLSI, Sony corporation, Rabaey book, Ismail Faiz book and their work, bakers papers and many one of this [FL] unless which I it was taken from this slideshare net website.

The last, but not the least there used to be serial in seventies called Columbus.

And the hero was the detective called Dick Tracy. I have seen many years ago us not in India dick tracy. Now in those days the electronics was very poor there was no wireless

in reality except the huge tubes and only there is a restricted band of one hertz or something where you can talk, that is what this radio ham had the problem ham radios because there are very small bands they were given.

So, those that detective has a watch which has a two way communication and here photograph and some small things we could do and so, in that serial they showed how to use that when this was not even thought that this can happen. However, Sony as it as early as 2006 actually made a similar watch, which can do to a communication it can do language translation, which is very important if you go to other countries including japan when I go e-Secretary, camera, music and electronic memory this is the vice president of Sony mister Subku Moto.

(Refer Slide Time: 61:36)

So, he was saying when he sees a Dick Tracy would has survived and he was in this he would have been turning in his grave, oh my good news [FL]. So, this is what has happened.
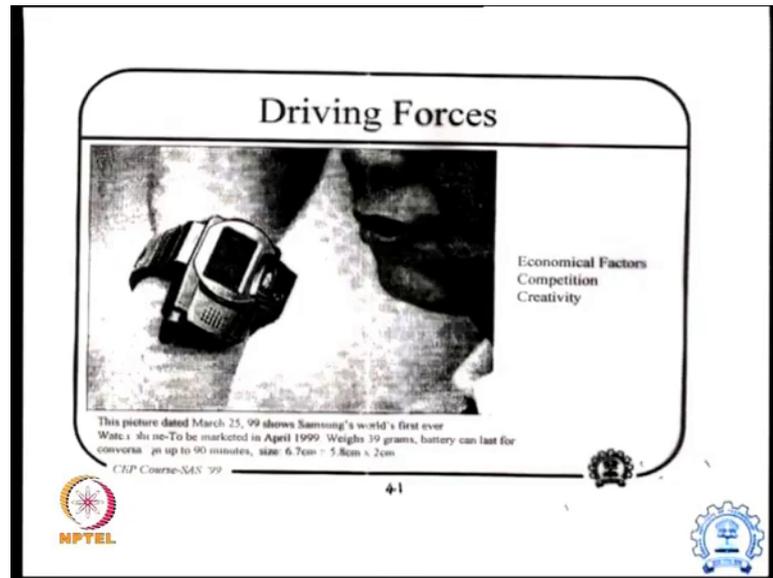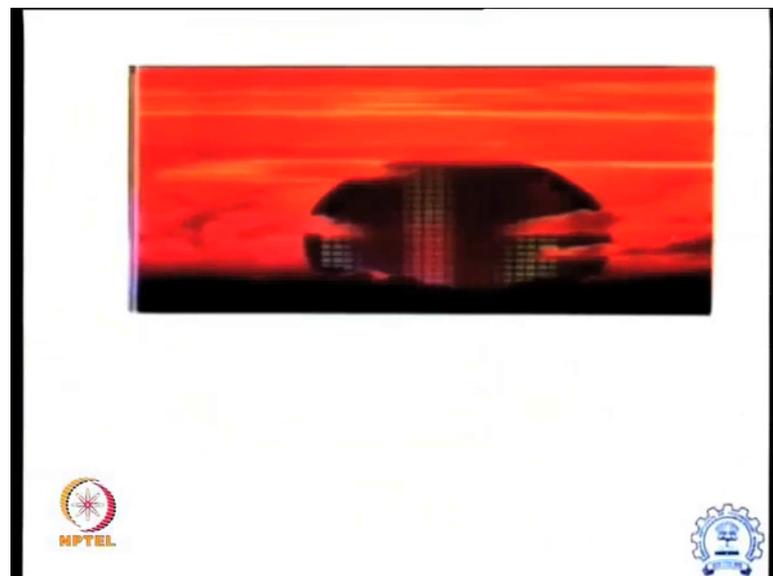
Even Samsung in 1999 have made a watch, which can do many of the jobs which Sony's that better than that 5 if ok.

Last slide, but not the least these are this slide I show every year.

So, many of you have seen it this is just repeat for the new ones. If you are an optimist or if you are a pessimist, you can look at the same figure two waves this is silicon wafer compare it with sun you are at the horizon, if you are an optimist you say only 50 percent

has come out fiftieth to come will see it. If you are a pessimist only 50 percent is here it may also hold on. So, depends on the way you look at the ICs here it is for you.
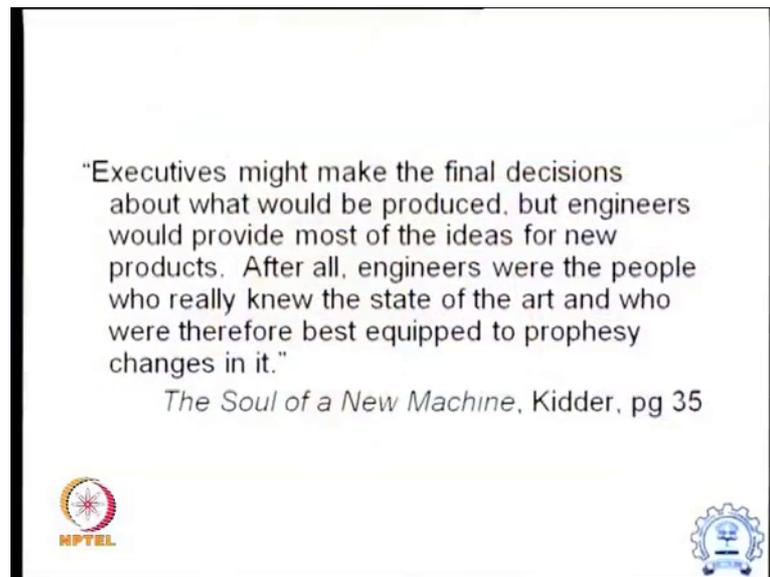
The last interesting slide, all of us wants to be in a good environment enjoys our life not being great work ok.

(Refer Slide Time: 62:47)
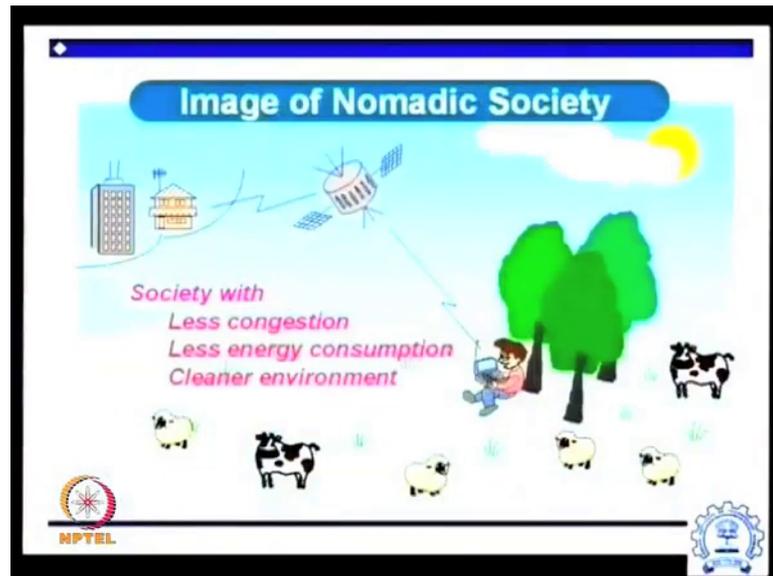
So, want to be in place wherever you used to walk in a good environment and still be connected to the world and do every job what would have been, otherwise that is nomadic life connected to the world that is what we aspire. For you all engineers who do not want to become managers.

"Executives might make the final decisions about what would be produced, but engineers would provide most of the ideas for new products. After all, engineers were the people who really knew the state of the art and who were therefore best equipped to prophesy changes in it."

The Soul of a New Machine, Kidder, pg 35

Executives might make the final decisions about executives managers, about what would be produce, but engineers would provide most of the ideas for the new products. After all engineers where the people who really knew the state of the art and who were therefore the best equipped or prophesy of the changes in it.

Thank you.