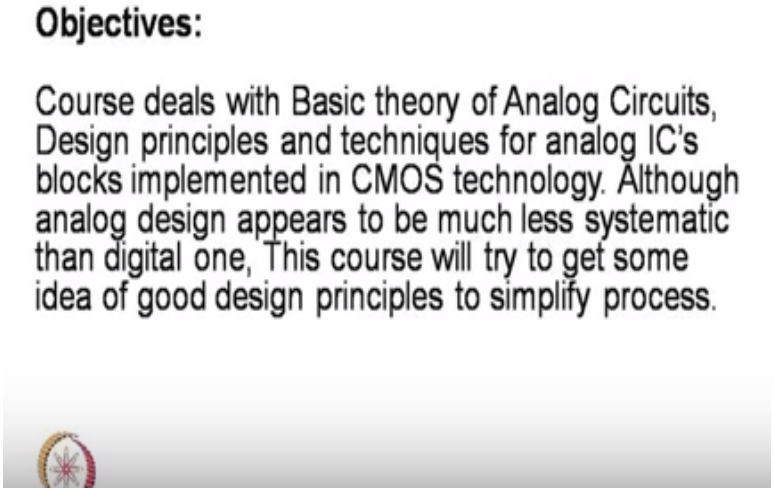
Analog Circuits
Prof. A N Chandorkar
Department of Electrical Engineering
Indian Institute of Technology Bombay

Lecture – 01
Introduction to Analog Circuits

Good morning to all of you, I am Chandorkar and I am the older package member of the department I am 29 years here well before we start let me tell you this course. Analog is the course, which will actually never leave you in your whole career in case you remain engineer irrespective what engineering branch you take, so please pay attention to analog because as the word suggests it is continuous in time and anything which is continuous and in time must be important okay.

Otherwise, you know world will collapse therefore anything which is continuous in analog and therefore it is very important.

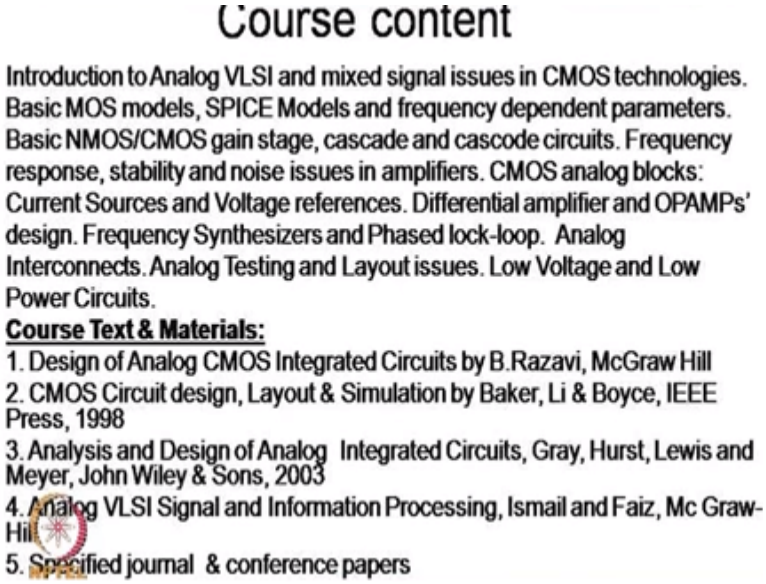
(Refer Slide Time: 00:01:04)



Before we start there are few things you should know my name as I said already Chandorkar, 6 credit course what did I what it is trying to do something that will try to see some of the analog circuits being implemented on bipolar as well as on CMOS it is very interesting to say that

analog design appears to be much less systematic, it is much less systematic whether some of those basic cuts, which make it unsystematic are clear to you.

(Refer Slide Time: 00:01:47)



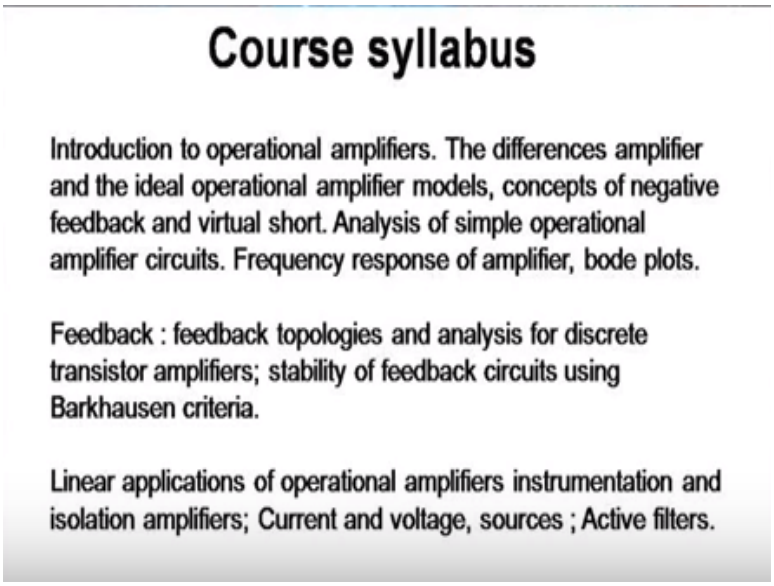
Some of the books which I will follow the first one you can see my name sitting there now her doubtful till I am not the author for this book so it so happened that they said Ross Smith asked me to defy Asia and other countries other than US it seems, so I had 150 pages to their earlier one in thousand pages and that is why my I am the third author in that book, so since I am now part of the game I said the textbook for me.

However if you have a book of Milman and Grabble old book by the way this Milman person does not exist and this is like in my time I think your father or their father maybe knowing the name called Theraja, I know electrical engineering by Theraja anything related to electrical electronics may be civil also he will write a book BL Theraja wondering how one person can have such a width.

So it apparently found that Theraja became book became popular so every other book from the same publishing house was written in the name of Theraja, so there it sells most well-known analog circuit person in the world he is Dean of universe and of course his is unsystematic to luck but very interesting those who are really looking for very strong physics circuits I think

grace book is the best and the fourth book which I like normally which is written by Nieman well you may be having read the his other book on devices.

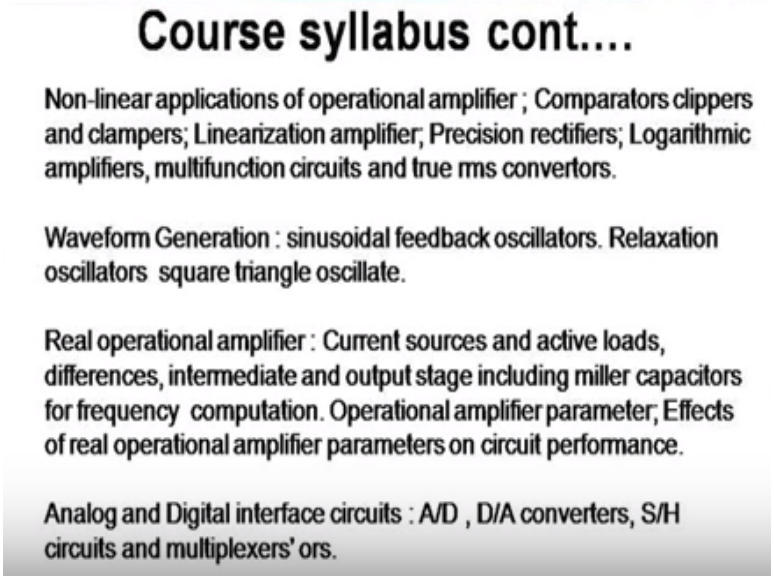
(Refer Slide Time: 00:03:43)



The same author has written another book on electronic circuits and design okay, this is the syllabus which our site also gives I do not have to talk too much about this something they are talking about operational amplifiers frequency response of amplifiers this word, which is Bode plot, Bode plot is a very famous feedback control system person and in 1948, he wrote the first book on feedback control and he actually described frequency responses and for a good reason.

Whenever I taught analog circuit I also like the twins the response part little more than others because connected to stability of the system and therefore of course you do not say but 90s, I was called Mr. Bode of Italy because of my fancy for this Bode plots some applications of like a is clippers and will also see some oscillators VL operation amplifier problems in amplifiers.

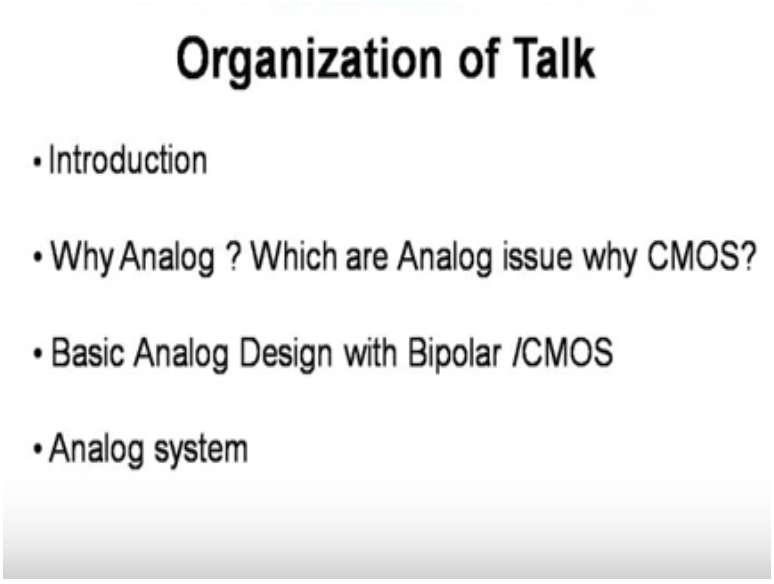
(Refer Slide Time: 00:04:45)



Normally, the old books have only bipolar transistors and their basic element but since world has changed to mass we will switch more on the mass maybe 30 to 40% bipolar maybe 60% less mass so that what is going on in the world now, so probably will though it is not specifically written here but I may actually switch more on master transistors and I am told you are already been taught that officially at least okay.

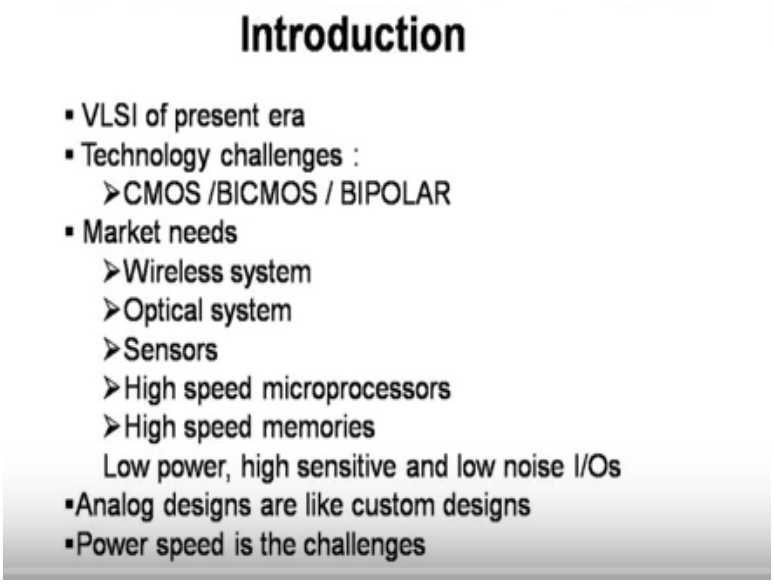
There you understood you liked it you do not know as yours but I am told you know it in the end we will see some more applications like A to D converters D to A converter sub loads and multiplexers time permitting oh okay so this is something about the course today.

(Refer Slide Time: 00:05:35)



What I am going to show you some slides which is just to tell you what is going on in the world okay so something I will talk today about why analog what are the analog issues why CMOS will just compare analog design with bipolar and CMOS and some systems, please do not feel that is this is irrelevant or something.

(Refer Slide Time: 00:06:03)



Whatever I teach in the class throughout my semester everything can be asked in the examinations including to this talk, so I just give you some what is VLSI what are the technologies what are the market needs why analog designs are very important and what are the challenges what VLSI has come from very large scale integrated circuits since 60s when the semiconductor chips have started coming in the market particularly from Bell Labs.

And then from takes on instrument we started counting number of transistor per chip, so we say okay hundred small-scale thousand may be medium scale ten thousand and about large scale may be millions very large scale, so that is the number we are talking this had happened because the dimensions of the transistor started shrinking from say 1000 micron down to say 9 now a day 28 nanometers.

So obviously if your dimension reduces the number of transistor in the same area will increase it is not so the chip size itself has initially I had a chip, which I made in 70s was one and a half and then by one and a half mm today one can have one and a half centimeter to 2 centimeters aside

so you chips for example Intel we sent delay on has around 940 million transistors core processor quad processor on chip and it has a memory of 16 K, which is called cache just outside another chip.

They are kept in the same package which is 4GB Ram design you can imagine what kind of density we are talking but good thing about all they this is only for digital and a lot of people still talk about thousand transistor know big sub trade you shipping normally I have referred to her use analog block the problem came because we have a technology of earlier was bipolar transistors and it is very ideal analog and a low performance.

In fact if you really want analog chip to work better you actually go for bipolar 2 reasons we did not do that or some companies still market for example some of the Nationals open 741 is still on bipolar not all of them, but some of them the reason why of bipolar loss because of it density limitations that because the size could not be reduced too much and used to consume huge power because of that slowly bipolar gave way to mass technology and present day 99% or 98% clips are on mass.

There is no system as far as nature is concerned which will not require analog so a new concept appeared which is called mixed signal analog plus digital analog may be 10% or 15% or even 5 percent the rest will be digital now the issue came that if you are a digital technology then I will prefer smaller dimensions because then it will be faster now I will go for, but analog says if it is a 1 micron I is variable larger it better for me now that means you are trying to put analog design on a digital technology.

Which is worse for it and now you expect that it should be a far superior it is something asking to much they parallel their analog designers left to themselves I hope they put 1 micron length, lengths it is great whereas digital will stay put 10 nanometers if you can 11 nanometers if you can so there is a problem and therefore the design and integrate circuit for analog plus digital has become very very crucial because of bad technology architects.

So that it actually does a lot of good things even with the digital around and that is where the challenge is therefore there was issues whether we should work on bipolar or CMOS and then in between someone said why not work together by CMOS there are many good things about bipolar CMOS process one of the thing it takes some advantage of bipolar and some of MAS but when I say some there will not many disadvantages are both alpha must become so you have to weigh whether this is important or that is important and then go for by Siemens only six companies the world have by Sigma technology no one else.

So what is the market is asking most of the market is saying wireless almost everyone of you I do not know if one of you I do not have a mobile you should raise his hand I do not think anyone will say I do not have a mobile because that is the only past and you are these days constantly put in here, so wireless systems have become so very important this is the market media.

So all whole challenge nowadays is to work for wireless system major money is coming from wireless market and there is a another system which is coming called optical system particularly a fiber communication passing a good data from say hundreds and thousands of miles wire layer does not work as good so you want a cable say fiber was invented now we are looking for optical systems another part came like this.

If you have an optical system obviously you are converting some data into through a photodiode into optics you have led and photodiodes you will convert one to the other from optical light to the elliptical to the light and now these conversions have more problems the fiber will do faithful transmission but what are more dense.

So the major research right now which has much of analog components here that optical analog components analyst laws for example are he looked into now the other area where analog circuits are very strong our sensors you cannot survive without sensors and then show some of them for the digital side you are looking for a microprocessors which is around see your desktop it runs around 1 gigahertz and you have to wait for our name our training.

Now what is happening because either there is a enough memory nor there is the speed of the processor so for this particularly game market all over the world including Sony Play station or Microsoft they whatever this they hugely certain micro speeds so you can see bad things also need something good and that is how we are looking for now around 6 gigahertz find the businesses normal Pentium fire Pentium you to use at least IIT has 2.1to 3.2 gigahertz.

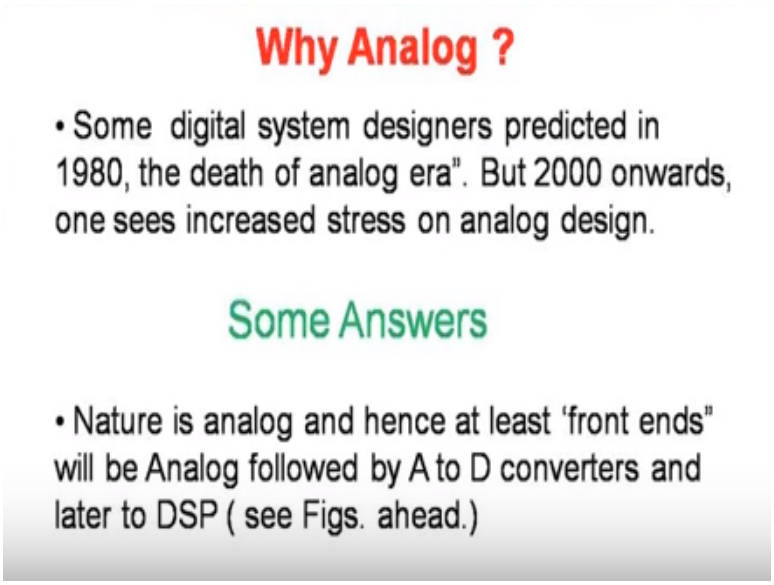
Now we are looking for 6 gigas someday maybe ultimatum is what we call as KU band can get there I should not say we I do not know because I may not survive to see that another area of interest in market right now is memories just now I said you want memories 4gb they are 16 N the requirement of memories and we want very fast access there are a lot of research going on.

In the area of memories and the most important area particularly IO input/output blocks which should be of low noise low power and very sensitive and these are the active areas of research the word custom means in VLSI there are 2 kinds of designs we do one is called semi custom the other is called custom.

Custom essentially will lead to customer so customer says I want the specs and you meet them so basically you are satisfied a customer is paying for it now good money but that means every spec he says you have to meet this is very difficult because there is always what we call trade off if you do this something else will be lost and to avoid that we are trying to get the best out of it.

So it takes huge effort huge amount of design time hundreds of man years to design a good custom chip so what we do okay we pre-designed some blocks and reuse it again is called semi custom so essentially NL of the lines individual design has to be designed every time and therefore it is called custom and I said custom designs are costly well it takes per unit is that clear the major challenge in either digital analog is power and speed.

(Refer Time Slide: 00:16:01)



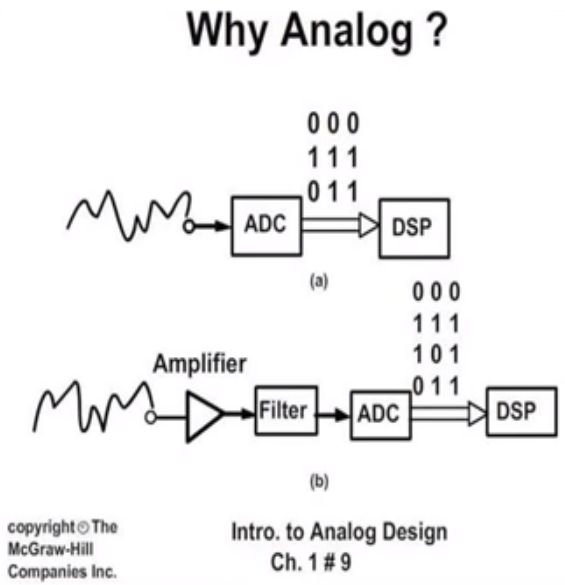
Speed in our case of analog we called bandwidth got a quick name a garage combined with larger data can flow on a same line larger bundles so these are the challenges now question arises why analog some digital system design by the way I have no fancy for digital or analog I teach all sorts of courses in last twenty nine I thought last semester I was teaching a VLSI design costume for postgraduate students before that I was teaching technology right before that I was digital system to second years.

I have no fancy for digital but when I sit on the this side I always have used the other ones as if I am now this side so this so called Digital Designer suddenly said oh then 1980 then the last ten years I find most of the research and most of the money has been now dated it partly because the wireless partly because of the sensor it was come exert very simple nature does not like digital you are not suddenly feel yes there was no tree today something gaudy.

It takes ages before tree grows nothing happens in nature with instantly that is why when I of course I worked in Tata Institute earlier what used to say generally thought must be right because he is suggesting steady state evaluations when nature is normally prefers to go steady it steadily but the big bosses are always saying Big Bang like a digit 1 or zero being analog even if you want to take that signal from the nature.

Which is analog and you want to process faster better whatever you call digital people say I need initial input outputs and then so I cannot avoid analog because nature is what I will do okay I will take that analog signal convert it into digital and maybe do our digital processing and then I want to display something I will convert from digital to analog and replace it back then but I still require A to D and D to A converters most of the DSPs digital signal processors do this.

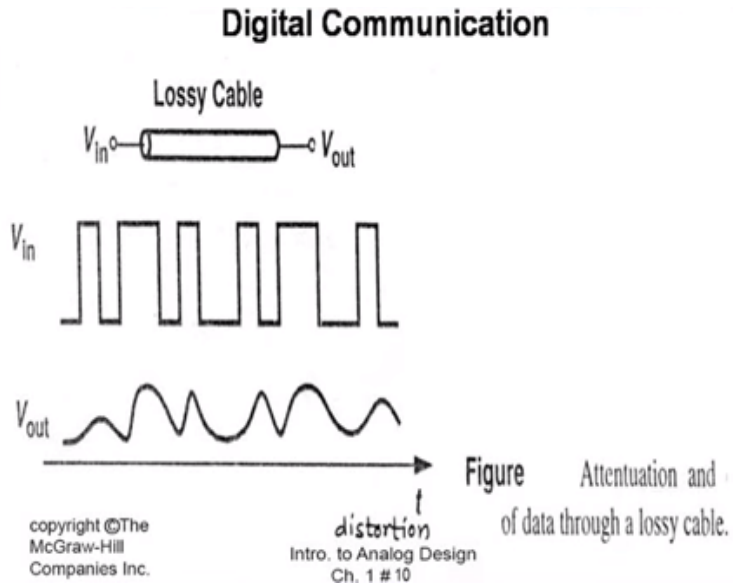
(Refer Time Slide: 00:18:30)



Here is a problem if I have ADC as I was saying analog signal what another essential is time varying constantly time varying signals are called analog, so this is analog signal I will convert it to digital data just to show you digital data then I will do digital processing the problem with this though it is shown as the same magnitudes in real life the analog signal since it is extremely be first amplified okay first amplified then a westerner the amplify it will get some other frequency components.

So I will have remove all those other than the signal I want so I may need a filter and then maybe I will further between C and process digital unit then if I want output analog I will convert it from DSP to D to A so you can see that these 2 parts even in otherwise digital system will be required because.

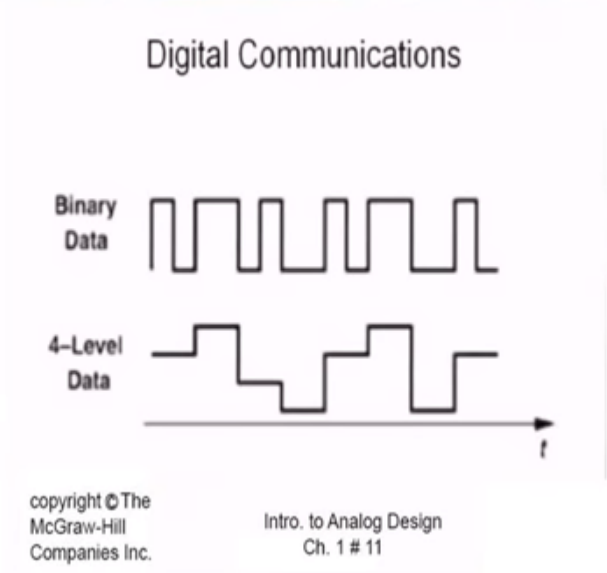
(Refer Time Slide: 00:19:40)



Otherwise I cannot process it there is a lousy cable like a copper cable or any other cable you said an input data this is the data you are actually sending because it is not a lossless line actual data which is being sent is this you can see it has a time period may be similar but its shape is how does it look like analog it does look like a analog signal so you sent a digital data but data received the output was more like an analog particularly this will be dominant if the frequency is very high if you are looking at coba guards above when the guard above it is more likely that the digital data will be smeared to become analog.

So even if I am fully a digital person now I have to worry about that the data which I am seeing being analog how do I process it so that it I still remain in digital that is another problem which analog people are now coming to help of digital.

(Refer Time Slide: 00:20:47)

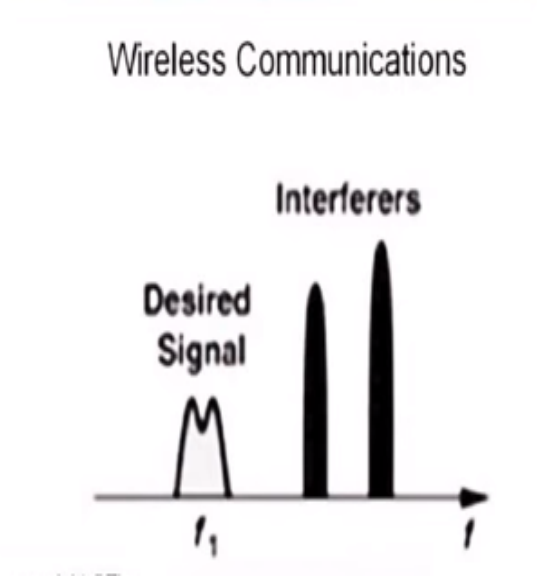


The way we do it we convert it by some reason for levels of digital data so a new technique over and digital how many levels we are looking last semester or 2 one zero upper level load now there is a trend going on in a very high frequency domain to look for 4 level data and if so you will require 4 kinds of census now because you should detect 4 levels not that it had appeared in the market.

This is what I say going to happen now that people may look for multi level digital data because that analog part then can you broke into more levels set up to only okay so the newer research is now converting this so called analogue looking signal into a 4 level are you and multi level people right now poor is what it being a template where did you why analog probably I am trying to answer why analog most of the disk which you use hard disk without hard disk you cannot survive or GB, 8 GB, 160 GB, 320 GB.

This is your data you are storing on the disk and what you really take it out is this lifted GB speeds are higher these days because you are making very high speed hard disk now and data acquisition actually smears it and the variation can be as high as 2 millivolt or some levels. Now again you will have to retrieve digital data out of this is called recovery so another analog circuit will be required to recover from this digital again there will be analog components.

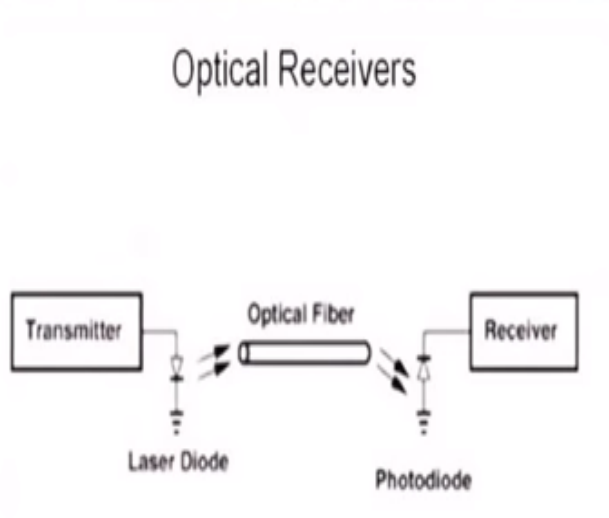
(Refer Time Slide: 00:22:31)



In Wireless you send a data at a particular frequency for example GSM sends the data at 890 mega hertz yeah this your mobile communication signal however whenever you see something like passing a signal there are 2 close by components which I will call interference now they are very close to the original frequency and at times their amplitude may be larger because of the non-linearity in the system.

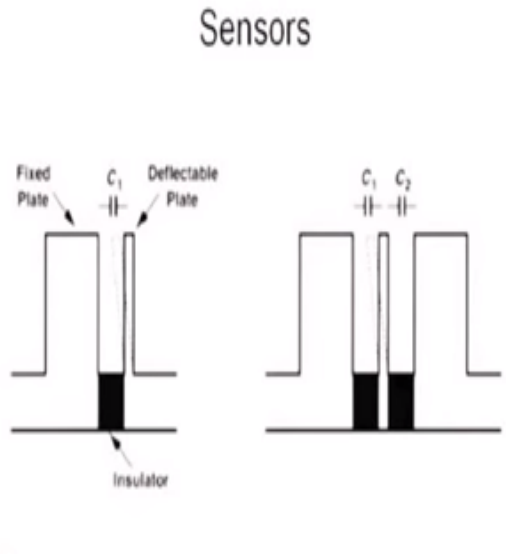
You may get additional components which will call that or some way harmony but these are not actual harmonies noise you may see and they may have larger so one of the major worry right now either you boost this enough so that the interfere signal is much smaller than the signal itself or shift this far away both techniques have been tried in the wireless communication and both require lot of analog processing.

(Refer Time Slide: 00:23:41)



Just now I said optical this is what optical receivers are you have a transmitter you have a laser diode large convert digital data or in a longer time to light you file through fiber photodiode which receives optical light converts into electrical and persistence much of the processing here will be analog.

(Refer Time Slide: 00:24:09)



In the case another area of interest as I say sensors as I said you want to measure temperature you want to measure humidity you want to measure all kinds of natural nature parameters I show you some other kinds of them soon the best sensors these days available are made out of another silicon technology which is called MEMS micro electro mechanical systems immense and the

most sensors which are now made available which are very small I do not know whether these day my time you know we have a mechanical courses company.

Whether you do electronics or you do anything so we are we have a Applied mechanics course we have a workshop we have many other things also they do on the surveying which I do not see anyone up even civil people do these days I am not showing anyone theodolite and their chain and everything maybe it is there I will not see so in the one of the move famous gauge which mechanical police calls claim which that is a huge bulky dynamometer they call because they made a lot of great large values of force as well as accelerations but they are variable.

(Video Starts: 00:25:20)

Nowadays sensors have very gyroscope but now they are not a big sensors vibration speeds so now we are looking for silicon sensors.

(Video Ends: 00:25:35)

And one of these method is to use capacitances with their measurements because in the silicon I can make a cantilever which can understand by acceleration by force will vibrate or mood on the variation in this is proportionate with the bending moment it which is proportional to sense which it was doing and the change here can be monitored at the capacitance if I have 2 plates here if I come closer capacitor larger if it goes away the change in capacitance is the measure of the force of the accelerometer.

(Refer Time Slide: 00:26:14)

Bio Medical applications

1. Blood Clotting Control
2. Implant surgery
3. ECG, EEG, EMG, ERG
4. Bio Chemical Spectrograms
5. Silicon Locket
6. Neuron sensors
7. Sensor Interfacing
8. Signal Conditioning

This is one more area which require lot of analog digital processing which is immense another applications which are very very important as I see is biomedical I will not do all of them but just to read for you there is a many surgical operations there is an issue because you have you will give an incision and lot of blood will ooze and if blood is loss too much the patient will die of it for the loss of blood though they keep spilling blood.

So there is some mistake a high as they call and it clock clots it but if it gives too much then they give clots in the veins itself so blood flow so the patient should not die he never made that area so we must keep monitoring the clotting level going on so this is essentially blood, blood clot control which in most of the heart surgery is very important because patient may die before you think therefore in such application to show you and analog proceeding is very important most of the it got a very good right.

Now and there is a surge going on for Pine Creek descriptions core heart because everything is right now is replaceable or kind I put 12 tantalum sheets are put here during this implants surgery got much of control is required which is continuous control and you need lot of analog processing all your ECG, EEG, EMG, ERG take insane brains any kinds of this body mapping all requires and analog processors and there is a biochemical spectrograms it takes place it does not suddenly happen it keeps changing its pH values.

So you want to know you want to see what is changing spectrogram is seen so during the patient is monitor when the drug is actually injected in such and this process is very slow so you need a small signal which is appearing in electrical has to be amplified noiseless because otherwise if there is noise in that you will get something wrong how to make it correct measurement of each another circuit which I had to Bombay has made other product.

We made well I am not the part of it Sharma and my earlier Rakesh lal and even the madam subha I am told these day there is a worry even of course I know you are too young and I only played touch would none of you will get your heart problems in your whole life it has been now found because of so called money-making business of youngster managers they actually are

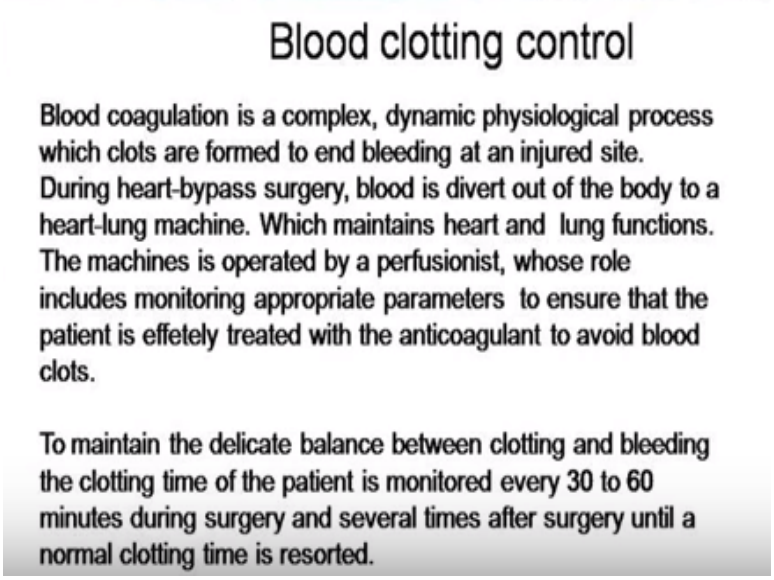
getting hard problems at low raise than 40 which is unfortunately how do we know that the patient is actually having some problems.

So we created a small kind of 2 Probie which is small locket which is put in goal like then it monitors it from the last you see if it is different than certain numbers the RF transmitter receiver circuit it will the patient is running on the track in the morning jogging and he is feeling problem now hence that it is happening to younger teens now another problem which and a lot of people are but his neurons your brain essentially works on the basis of neuron signals.

And now they against head all neuron processing is essentially like analog I will show you some all time a neural network which actually replicates a neuron behavior is like it open character so you can actually think that a open can replace your is equalent say what that is what is important that neuron theory should on the hard board using opens another area just says you know anything you monitor inside the body is called lab inside your body lab chip as they call it will keep monitoring everything for you a week.

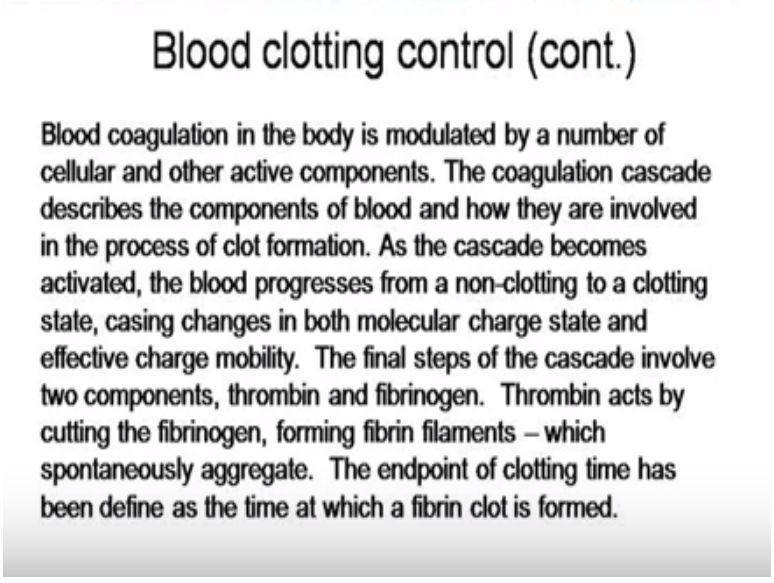
So you need a good or for that at the end of the day whatever signal I get I must reduce is very small signal I must amplify it I must filter it I see to it the it should click out the original signal as good as possible that is called signal conditioner so these are the blocks these are the areas where analog is used yes I read quickly okay.

(Refer Time Slide: 00:31:32)



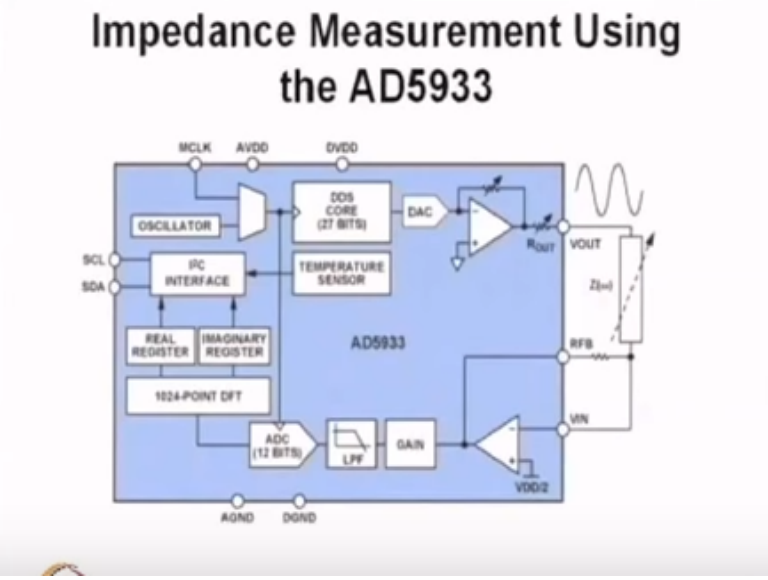
I already said the person who does this machine is called perfusionist whose role include monitoring appropriate parameter to ensure that the patient is effectively treated with anticoagulants to avoid blood loss and for at least 60 minutes this is thing monitored so okay this is more to tell you what kind of thing happened there is a thumb brain and fiber genie to such parameters we keep monitoring see what is the but basically what elliptical people monitor it actually changes the impedance when it changes this so all that we do is to monitor the blood impedance.

(Refer Time Slide: 00:32:06)



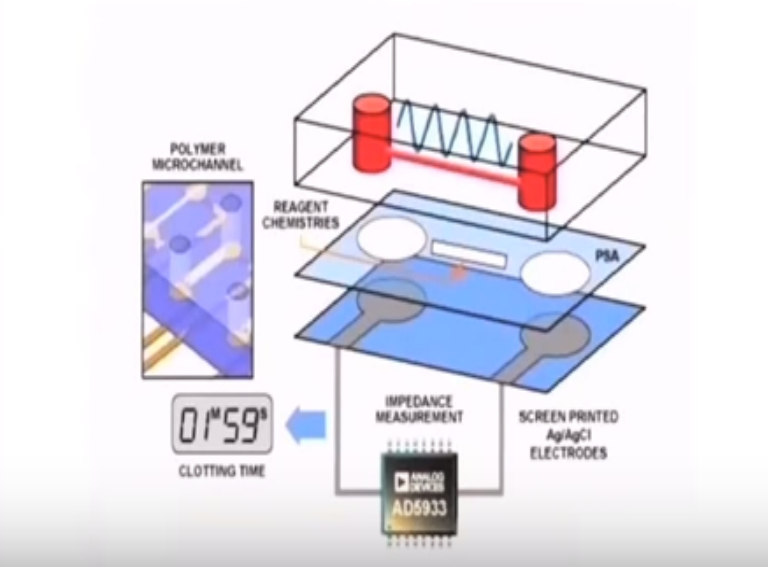
That monitoring we know whether what is the cutting level like nursing and then we can control it that hyper on how much to inject or not in there through this feedback system okay.

(Refer Time Slide: 00:32:21)



So here is an impedance measurement system which is based on another device a chip called PI certain digital part there are certain apart this is your oscillator then there is a course multiplexer and there is an interface then there are digital block like registers DFTs but they can see there is a ADC there is a filter there is a gain amplifier okay and you can see signals are analog and you are monitoring the impedance the blood clot.

(Refer Time Slide: 00:32:55)

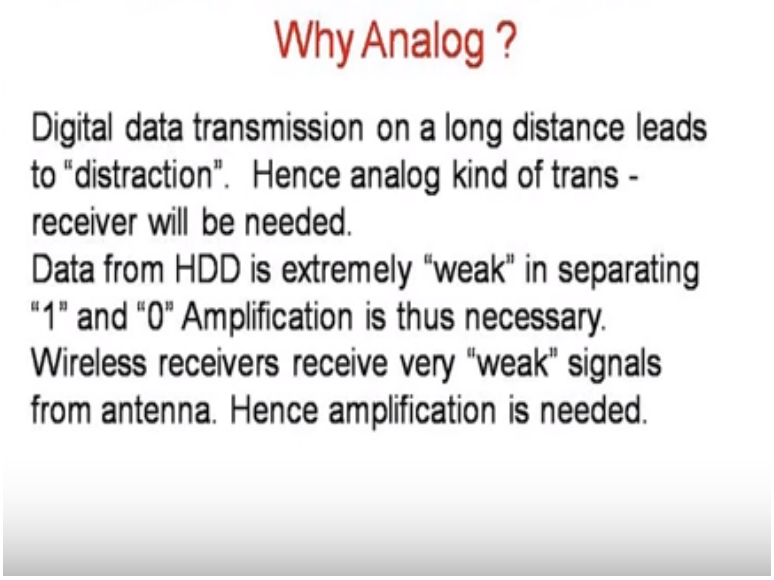


How it is done it is this is how it is done you your blood clots are kept here then it reacts and then it keeps finding the impedance and then this is done in meds now the chip is outside this is

the main structure and the whole processing is in a lot plus digital because something you are to control by digital okay.

So you can see that only giving you one example why analog cannot be ruled out that everything is digital why analog this is a requirement where analog cannot be removed okay.

(Refer Time Slide: 00:33:34)



I just said all that okay another thing which people say digital data transmission on a long distance leads to destruction that is noise continues as NL kind of transfers will be needed now question arises why we are not doing cross and analog of transceivers this was known to us many years ago 60 we knew analog better than digital.

So why we not continued with why we major where he came that analog signal actually died town as they Move to at the on the line because of loss it has to need a repeater if you see optical fiber every mile there is a repeater so if you do same thing with analog yeah it can be done but then again you will have to improve it by its low noise performance filter it out cost upon it is not that it cannot be done it is just the cost in one and the power supply period.

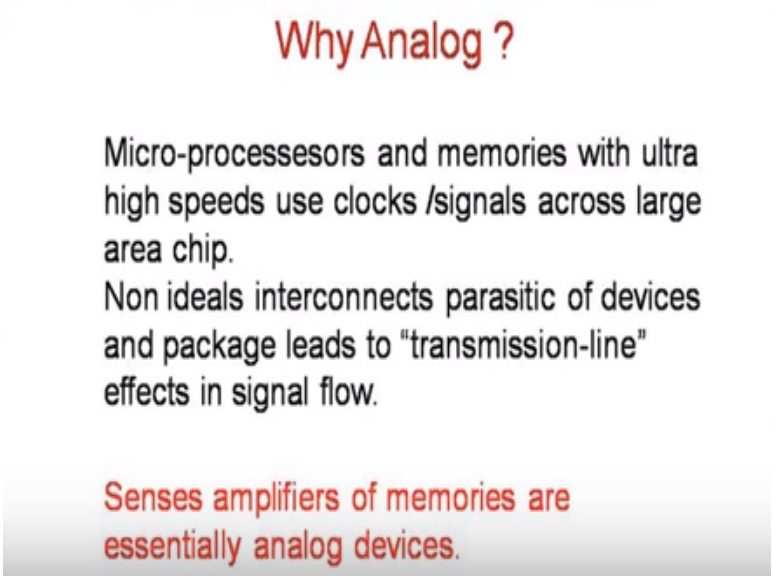
So because of the cost involved in this analog of receivers have lost consciousness lost to digital or digital signal can go far distance compared to analog and will require it Twitter after maybe 20 miles or 50 miles or 100 miles that is where why are we have a cable why not use transistor

which are far superior in performance so at least locally we may come back now for its own vitality of best performance sensitivity you may come back to trial analog transition assistance**.**

For example in normal hard disc the they were little names you very high speeds on this how come so you need now something to amplify that similarly for wireless antenna you and for not digital antenna signal which you receive this depend on from how far you are away from the tower course powers are not good for your health that is what everyone is now saying but I always say body is immune to everything after something.

So probably this fore called our radiation will finally become immune to that hopefully soon maybe one yeah he would ask me other day that you stay in Bombay radiation from the PRC and our opponent I say I think our health is better now because of radiation curing something hopefully that is the way we should look okay.

(Refer Time Slide: 00:36:07)



I earlier said micro cell memory with ultra-high whose clock signals across major worry a chip is 2 centimeter I just said now what is the length of interconnect on Intel chip anyone yes what is the length of integrant with a line taking signal from one to the other what is the length it actually transfers through on a chip typically maximum links available on signal chip how much any one of you guess nanometers typically Intel processor has one kilometer length of interconnect electron chip okay.

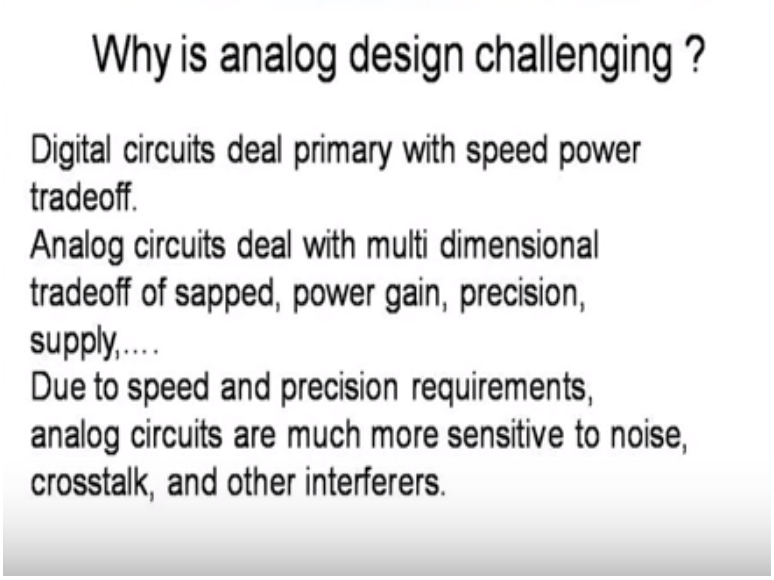
That is something you must understand that we always think why over here on a chip itself I one kilometer now if that is so the signal will not have integrity going from one point to the other that is our major sell so the clock which is running from one end to the other actually drifts away okay so let us say what is drift where means at T=0 let us say one has to come at some point it will be T1 0 plus point something because it is get delayed by them this is called jitter.

Jitter is the major worry for digital data processing forget about anyway then the recovery of this can be done through what is called as phase lock loop which is analog block okay that is why for clock recovery we will require it analog circuit because you are running a very high speed signals on a large length of this is like a transmission line so all this memories have something what we call sense amplifier.

What is sense amplifier can be let us say memory you are read let us say you are storing 1 as out where you call sense I know the cell has one it takes long time because this wire is long enough so it has a large capacitance it takes long time before one word it wishes I do not want to know whether it is fully one or not I have already pre charged this line we say 0.8 charging process crosses 0.6 I will compare if it is larger than point.

I have one I will not bid for it to go for one this is called sense sample since amplifier is a comparator which is analog so even in the so called hard memories the major research access time research is only on analog component and not so much on the cell is that clear to you.

(Refer Slide Time: 00:39:08)



Why and in the case of digital the circuit deal primarily with speed and power I want 4 gigahertz 5 gigahertz data flow and I want preferably what power consumption pre-fitted I mean I want zero what I know power cannot be zero so as low as possible microwatts but certainly not vats typical cheap consume 40 to 100 watts of power okay micro basis of chip consumes around 40 to 100 watts of power this so the whole research right.

Now they are looking is how to reduce the power but there is a trade off as soon as I reduced the power what do I reduce essentially the current if I reduce the current power will go down B into I okay but if I reduce the current the time taken for the capacitor charge with the lower current will be larger CDV/CDT smaller for T it takes longer okay speed there so there is it a lot.

So now game is I want high speed but I do not want to be you about that senses thermodynamically it should not be possible if you do not give me this I want you the other so how to fool thermodynamics is all our tricks okay if you learn my digital course someday I will tell you how I am fooling circuits I am fooling others beating as your thermodynamics is avoided no it cannot be somewhere else I am doing something tricks as far as you are concerned.

I improve the speed I reduce the power where did I spend I am not telling okay where I must have done some tricks I am as far as you work on money I speak low power that is where the research in analog these are not the 2 parameters we are worried this is unfortunate we worry

about speed, power, gain, precision, power supply variation in that and many others at least five six of them you need large bandwidth which is called speed you need very precise because Y presides because analog is time varying signal any change there will be seen at the output okay.

So precision means 1.6 million means 1.6 million 1.7 get bit time spark so I am worried that what I say I am must get that precision is very important in analog not so much in digital why I say so because there is a noise margin one can be recognized from VDD by to VDD and zero can be recognized by VDD anywhere is fine here anywhere means nowhere and that is why analog needs extreme positions of course there also will beat the system do not worry everywhere like all IIT brightest among them they feel.

So I do not know whether they are hopefully they are you beat the IIT system not that you do good or bad you see to it that whatever we come out with how to beat it ok so I have full faith in you as well whatever they I will try to see you should will do it you will do it some way or the other that is the IIT level so ok very again as I say they are very sensitive to noise what is crosstalk today unfortunately for me.

There is no crosstalk maybe this is your first lecture you are worried about me good keep worry anything you talk there if it interferes on me my talk its crosstalk so 2 lines are going one date on this one data this may interfere the next line close by because of coupling will do mutual coupling particularly inductance mutual inductance this is not crosstalk if one data is going in this direction the other is coming in this direction the cross drop is highest both amplitude opposite.

So maximum definition so that is major worry in this interferers cross talks sensitivity to noise all these worries have to be satisfied when you design analog that is why analog designs people started difficult other worry of analog is even worse many times analog circuit books are called linear circuits what do you understand the world in here why they were called linear circuits yes linear okay but in math is Y=MX the linear system if I change X to 2X Y will also get doubled FM remaining constant okay.

Linear systems is that clear why therefore similarly analog circuits were earlier called linear circuits because output voltage was proportional to input voltage any meaning constant V0/Y is constant straight line this is called linear system but our assumption is that the device property is always like this that is why I translate input to output proportion but in real life you are learned bipolar devices you are learn mass transistors I side so there is no real real linearity in the mass or bipolar characteristics.

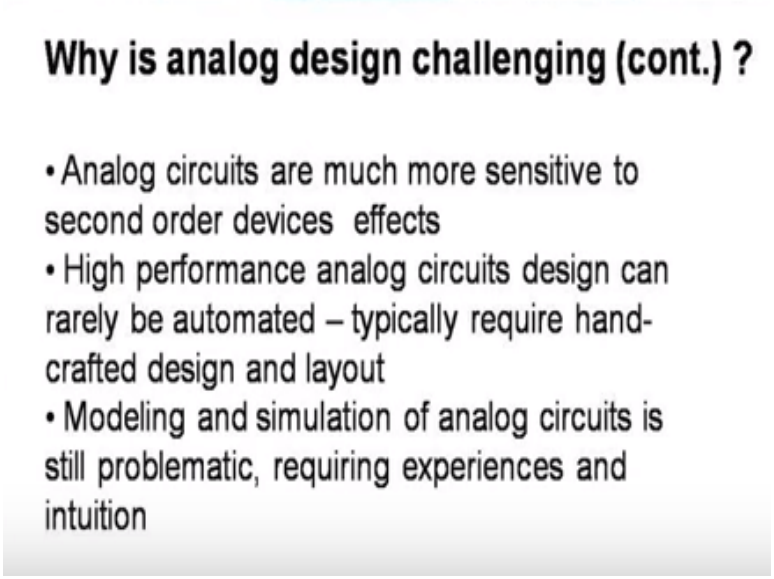
So there are regions where output current and input voltages they are not linear or input current to input output current things which are not linearly connected if they are not linearly related then there is a second-order non linearity appeared so to say Y=A0X+A1X square those no linearity now this X square term will create that say sine Omega T or the signal X square will create what terms sine square Omega T which in terms of plus 1 minus 2 sine square Omega D sine Omega T that means.

Now you have Omega T turns and 2 Omega terms also appearing is that harmonic has applied so part of the power has lost will second harmonic is that clear.

So in the case of analog here a very small range which is as soon as you increase the amplitude even a little more you are in a nonlinear range and part of the power is anyway lost second or third higher so you are always worried in if you should remain within so called that linear range otherwise you will immediately get to second orders device problems okay.

These are very important effects we will see how to minimize them but not every time you can reduce to zero level because of this so called smaller range.

(Refer Slide Time: 00:46:24)



So many effects it wants to do it is very difficult for do automation like digital in digital there are all kinds of software available so much so nowadays there is something called silicon compilers I give a statement I want to do this under this condition it should show me this and a chip can be designed without our intervention all simulators can do this it will actually find out what you want and it will finally give a design for the chip this is full automation course not the ideal.

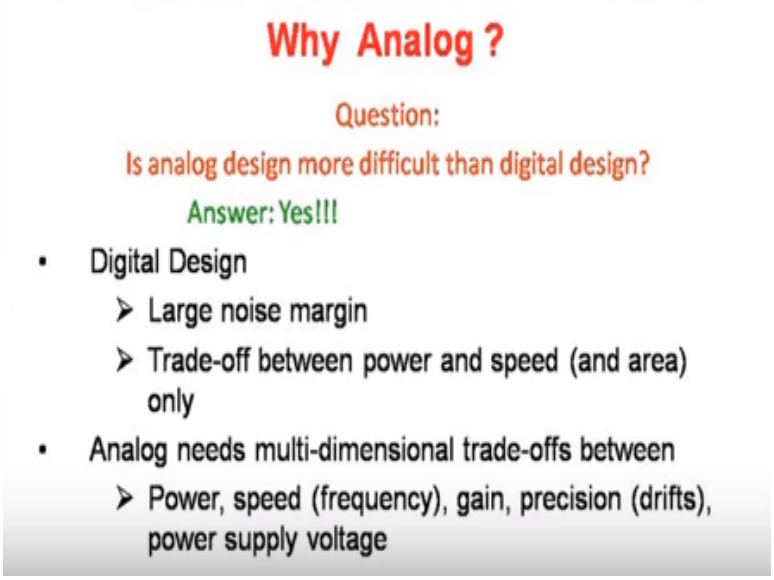
We still interview interfere everywhere so that we remain in charge if everything is done by a computer what we will do so we keep saying no human intervention is essential otherwise they do the possibility that automation is great in digital hardware or digital simulations there is nothing so called fully automated analog designs or analog systems. Design every time because it is very problem mistake every small problem has to be individually handled.

And fixed that is why analog is interesting may be difficult and much of this you know what is the way people do it not essentially always by reasoning mostly by intuition and experiment I saw who is very guarded taking economy forces require development on a circuit in mainstream rigid person that is what I said and that is creating major problem because technology of digital particularly at 45 nanometer down is worse for analog device but we have to work with them.

So we have to integrate analog digital on a digital process rather than on a analysis which would have been ideal because if I want okay I am only why should I put everything else I want only

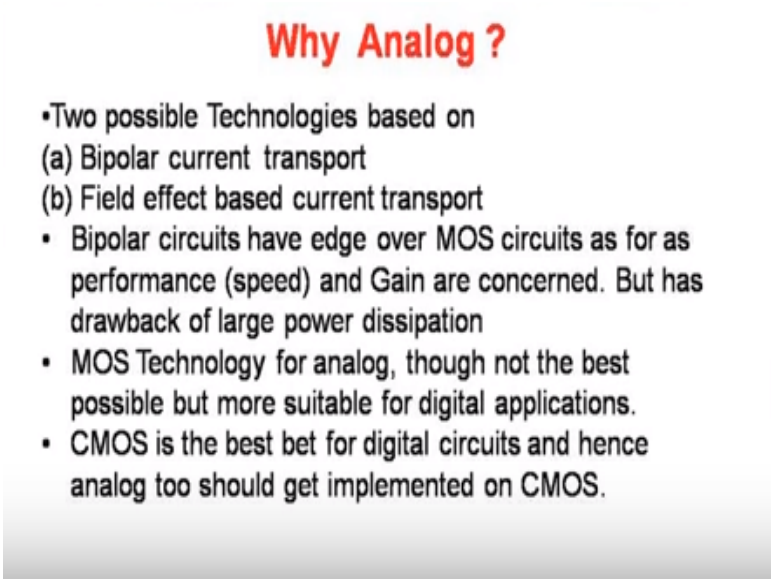
this I will give very good to you but I cannot because they will say no this has to sit with microprocessor this has something else put your block here and one there is issue so there is a difficulties in analog design therefore it is a challenge.

(Refer Slide Time: 00:48:56)



So what is my uncertainty is N I have designed therefore more difficult than digital design my experience for 29 years says yes because digital design has a large noise margin okay you can have 3 way trade off only power speed and maybe area whereas analog needs multi dimensional trade-offs power frequency gain precision power supply and many more okay.

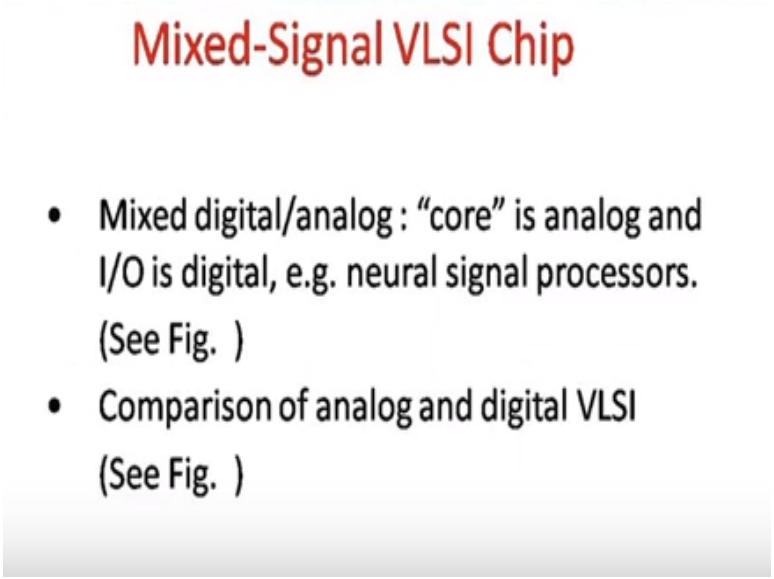
(Refer Slide Time: 00:49:18)



We are already done sorry there are 2 possible technologies which analog circuits can be implemented using bipolar current transport there bipolar transistors or field back base current transport which is most understood by a polar circuits have aged over mass circuits as far as performance is concerned or gain is concerned.

But how they drawback of large power dissipations where as mass technology for analog though not the best possible compared to by below but much more suitable for digital applications CMOS is the best bit for digital and hence analog to should get implemented on CMOS not that digital but that is the mystery.

(Refer Slide Time: 00:49:57)



There is just mostly the chips will be mixed signal both analog and digital together I can usually say and I will show you some figures okay this is a weak signal neural processor this is your digital signal noodle digital signal processing this is D to a converter it is analog near neural network precision of neural processing.

(Refer Slide Time: 00:50:13)

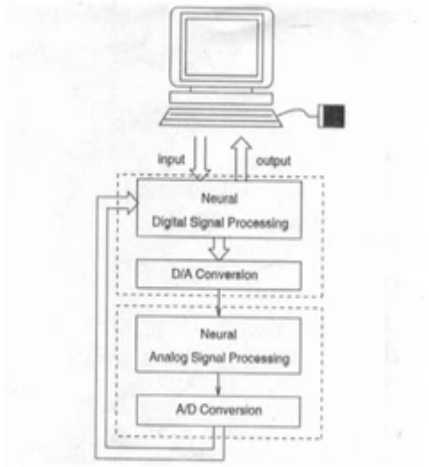
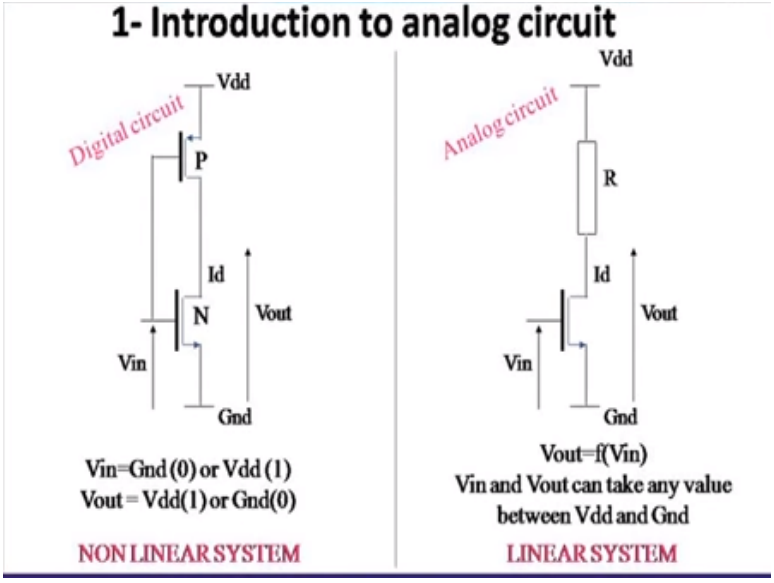


FIGURE
A mixed-signal neural processor for image data compression [2]. The digital part is a VQ codebook generator and consists of a host interface and timing control, a vector address handler, an input vector, a codebook, and a self-organizing trainer. The analog part is a neural-based vector quantizer and consists of a synapse matrix, current summing neurons, sample-and-hold circuits, WTA cells, and a digital encoder.

This is a to D conversion this is a processor was designed way back in 1994 or something which still works we are trying to replicate brain functions now we are trying to see how brain works so tomorrow if you have an accident for some reasons you have a damage to your brain can I put a chip supplement that part this is what we are looking for is that clear by this insert there is a worry there is a too much traumatic situation these days because the cars are too many speeds are too many 2 wheelers.

If you are driving please take care of old person like me crossing a road at the main gate I always pray God every second because I do not know whether I will cross finally when this motorbike person will not throw me he does not see signal, he does not see people I do not know he only sees speed, so I hope some of you have a bikes we have banned and told but I still see hundreds of them in case you are driving please take care of old people like us who still may want to throw at least 2 more years.

(Refer Slide Time: 00:51:32)



So this is something what you are right now looking for okay this is coming quickly I show you introduction to analog circuit you can see here this is a nonlinear system and this is a linear system can you tell me why VN is ground or VDD is one V out is either one or 0 the reason is both are transistors and both are non linear components so V0V in when you go for beam from 0 to 1 both transistor will not remain in the same operating mode.

That means one may be in linear other may be in such as other may be the other both maybe saturation both maybe since the characteristics in all 3, 2 zones are different there will be lot of non-linearity in V0V being characters called the transverse. They are loaded on transfer characteristics so that is a nonlinear device but in the case of analog circuit.

(Video Starts: 00:52:39)

We only operate this is the transfer characteristic of an inverter which you just now see CMOS inverter you can see from here to here V0VIN is non linear because in here saturation on catch addition other is in saturation both saturation other opposite happens here. In the case of digital signal goes from 0 to say VDD input goes from 0 to VDD analog actually works only on this dome they are relatively V0V linear you can see the available input range to me how much few millivolts you get the point because during this few millivolts only V0V has relatively linearity.

(Video Starts: 00:53:30)

So what does that mean the input signal in analog had to be small signal otherwise it will not remain in linear zones and that is why if you operate bias, your circuit only in this range let us say this is my biasing voltage then I can apply an input signal red which still keeps output such that V the analog differs from digital, I go from here to here analog I remain only here okay and therefore you can see me near circuits below always limitation of small signals.

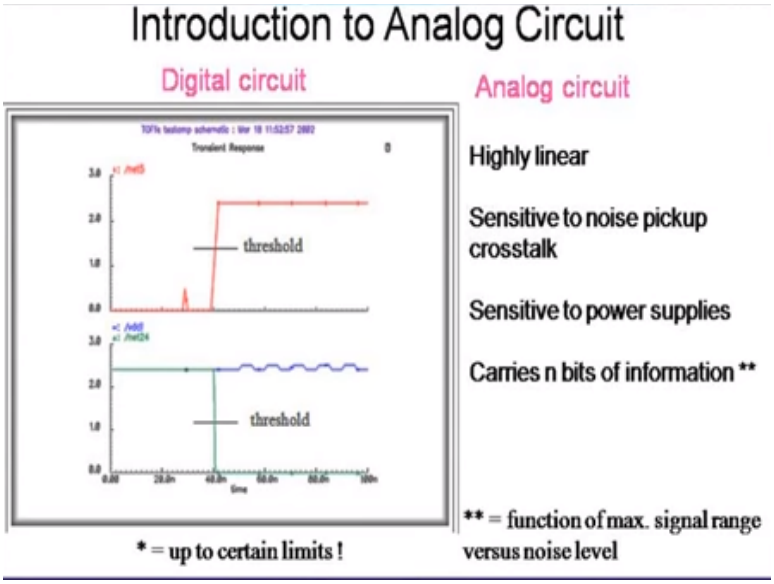
It cannot have because you can see if I have this large signal you are in non linear areas that clear you there for analog circuits. normally we have very small signals limitations because of course you can go out then what will happen the power will go into other harmonics more than maybe fundamental the frequency you are to Omega T 3 Omega T 4 Omega more than non linearity X square X cubed x4 more third fourth, fifth harmonics will start appearing plus another may appear Omega 1 - Omega 2, Omega 1 + Omega.

Interference and therefore, and a lot of people should normally try to operate themselves in the linear mode and therefore signals are always limited is that point clear to you that is why I say this is so can see if you operate in this then you can remain as an amplifier and then you can say you are in linear circuits.

Just to compare again digital are highly non-linear, but very high noise immediately I just said VDD/2 VDD1 0 to VDD/2 is 0 huge noise immunity you mean to power supply variation if I if one will supply become 800 milli words or 950 million then who cares that we then know the margin whatever happens let it happen I damp clear and it only carries at a time only one bit of information circuits is highly linear extremely sensitive to noise you can just see if that signal has some more noise.

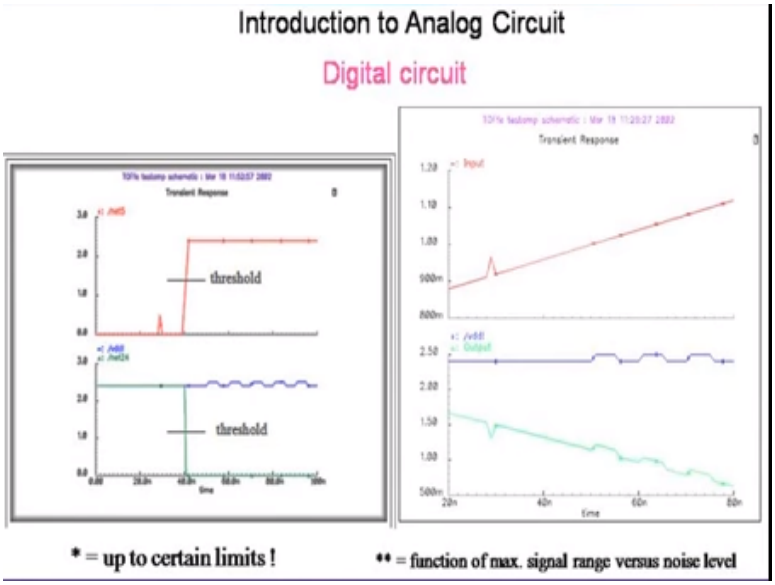
It will transform immediately at the output any variation in power supply means bias point will vary means one side may become nonlinear one side may become linear so very sensitive to power supply value and carries any bits of information the sense the analog so it is an N bit of information is going in one go okay that is why it is very good essentially okay one more figure will come here is the advantage of digital.

(Refer Slide Time: 00:56:47)



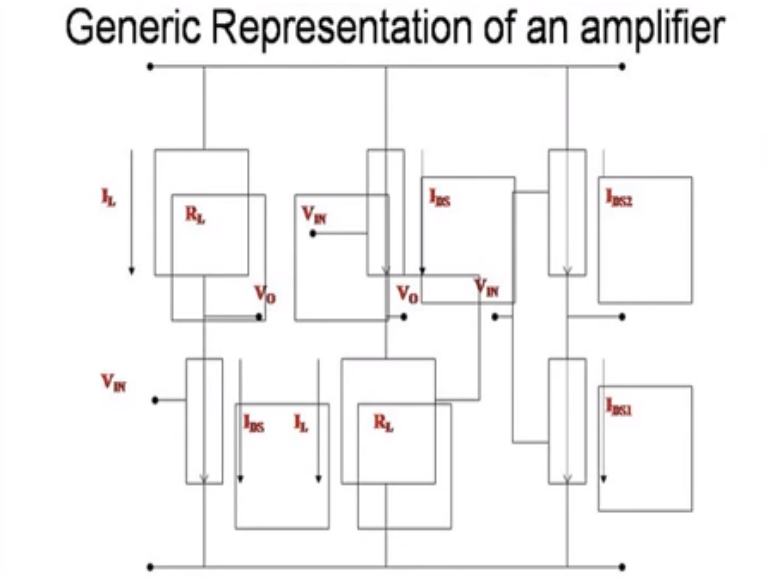
You can see it is not very clearly visible but maybe we are read from here this is an input I have put and this center line is threshold so anything about is one anything below you can see that is a small variation is occurring below okay, it is less than we still recognize a zero but if that happens and this now you can see from here this will be visible to as soon as it was it also jumps so anything in digital is acceptable where I then enter up it is not acceptable okay.

(Refer Slide Time: 00:57:38)



So this is your VDT variation so you can see we need a variation will also appear at these signal outputs you can say this is my VDD variation this is overloading because that will change the bias point that will also show you the different games different outputs so worried in analog is so called noise over reading every time if you do not take enough clear in digital a damn here okay.

(Refer Slide Time: 00:58:11)



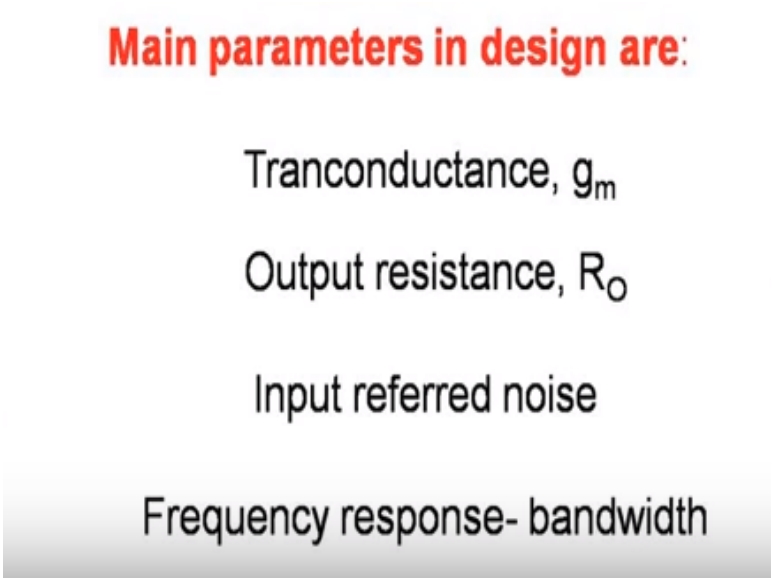
Okay radiation some other day I do not know it is visible to you I okay maybe just tell you there are 3 ways amplifier generic will show you this latter 3 possible way of mass realization of amplifiers okay so what we have to consider in analog is handling a positive negative signals in digital gear only 0 to 1 is that correct in analog –VDD -VDD + V so no power supplies are signal maybe a pair plus minion sign sinusoid has square head.

So you need your radius I just now told you in the figure where do our bias is very important because that will do that - I mean no immediately on linearity so, I must bias it correctly so by seeing is most important aspect in analog design because that may decide me all of the power delivered to the office linearity is essential because there were I am what did I was avoiding I do not immediately get you I lose power in harmonics time.

I need linearity I want noise tolerance sorry the word is slightly I made a mistake I want lower noise not tolerance this essentially means it cannot all hit larger I mean I it should not it should tolerate larger noise but does that happen so you mullet will have a very low noise tour length in normal system therefore you must design for it that at least tolerate this much months nothing should drift too much power supply should not be one volt and certainly pointed would everything will hear my score drifts the problem with design aids.

In case of digital as I said we can now pre design pretested blocks I have a multiplier I have a multiplexer I have an alder I can once design for a given technology store it and whenever in a larger circuit I just replicate that nothing happens in analog that there is no standard sets every blog you design every time okay and difficulty in designing low voltage low power because larger the currents larger is the charging of capacitors.

(Refer Slide Time: 01:00:41)



The current Hoonah modular power paper there so that will have a major to make it local for 4 important parameters will be looked into designs one is called tranconductance what is trans conductance by definition tranconductance GM output current divided by input voltage or change in output current to the change in input voltage Delta I/Delta V is GM hmm so one of the major parameter of design of analog circuit is the GM, and you will see that the GM is proportional to I semi current.

So if you want again which is gm x RO need larger gm so what does that mean the other GM will come from where larger currents larger cause so gain at the cost of power no other way we will see you alternate way then we also want to control output resistance some systems need very low output resistance some systems connection needs very large output is it can be very output resistance of the system the third parameter of interest to me is called noise.

Which is called input referred noise now this is very interesting word while it is not called output referred noise there must be something in it so we will worry about input referred noise and forth but the not is the most important part other than the gain is the bandwidth larger the bandwidth higher frequency performance is greater bitter and therefore larger bandwidth SAR and we will see a very interesting thing will happen gain into bandwidth normally is constant what do I say gain into bandwidth is normally quotes is constant.

Now I will see that can we beat this word normal otherwise what would happen I increase the bandwidth I lose the gain I increase the gain I use the one okay so can I beat this system I will say it and not loss the bandwidth but I have boost again if I had done that I have beat this so called technological constraint every technology said this is the maximum gain bandwidth possible but we is here technology the technology.

Show you how do I do it at what cost we will see we stop we then I politely I gain something but I will see that this so called constraint will beat what is the constraint we said and into bandwidth is constant but we will see to it cat will take because it is not possible again I repeat bandwidth increasing and gain constant is not very easy but gained increasing without losing bandwidth is possible because bandwidth is related to capacitance of the transistor that I cannot touch okay.

So I will say okay maybe there is enough we talk today will have some flight latter another half an hour lecture we will continue on this and we will show you that little more design issues what is happening say then have a nice day take care.