Analog Circuits
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Lecture – 02
Two Parts of Review of Analog Filter Approximation

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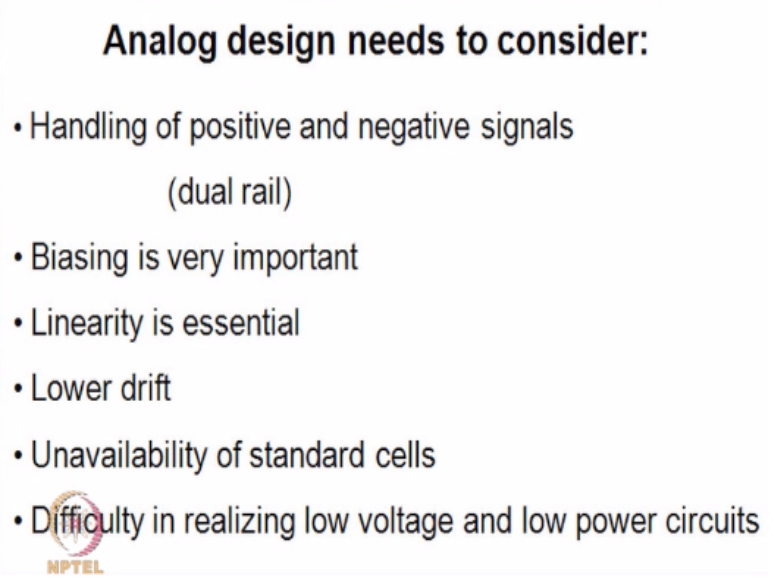

Okay, good morning all of you we will start over proceeding today you all should have following things in mind all electronics steps there are two signals which are always omnipresent when of course is the signal, which you are which is your input signal the other is the noise and it is the signal to noise ratio, which decide whether you will get the signal as the output or the noise as the output okay.

In particular low amplitude low frequency signals, which are more like as we call it is more damaging to the performance because they can be passed on in almost all systems why did I say so so when you keep talking very small volume you think you are actually not creating noise actually it creates more noise then you shout okay this is of course a fun part of it let us consider what we were doing last time will still go through a few of the slides and start in earnest the course itself okay.

Why I want to show you further because this is my belief that many of you question us over the years that what is the purpose of all this of course for individual it may be varying differently

you know for some people you are here because your parents asked you to appear in JE and for good luck you came here for some you are expecting some four years to pass with all somehow that four years pass or dual degree student five year or unfortunately for them.

So, they are just waiting for that time period to be over if it becomes T is equal to and immediately they will be very happy but there may be 10 percent may be little more I hope so who are really interested in what we are teaching so this course essentially in addressing mode to those people who still believe Engineering is interesting I also useful in your career if you can increase this number to 90% someday I think it will be great success for you as well as for me let us start.

Analog design needs to consider handling of positive or negative lastly we did last time we said so here is repeat from there in case of analog and I will show you later biasing is very important linearity is essential I this one problem I will solve today I will live on explorations I derive for you we just now said noise you know since both signal and noise will go through a system and if your noise is higher the system does not tolerate it and then it will pass more noise than the signal.

We also want lower drifts the word drift is something you are supposed to go on a particular course and you move from the course it is called drift so let us say power supply voltage has to be 1.5 volts and if it dips to 1.4 are 1.6, you may have much more problem in at your hand when you saw the circuit performance similarly there are many other parameters can drift temperature for example 20 by degree is what we assume in all 27 degree we assume 300 degree Kelvin, but in real life and circuit start functioning.

Due to heat, there is heat dissipation in device everywhere and the board itself will get heated and the temperature may rise to as much as 35 to 40 degrees okay, so the performance in the circuit has very strong dependence on environment around and that is called drift problems. Of course in many cases there are two kinds of problems one can get is called systemic that is we can predict if this happens this is going to so we have a priority.

We know this is going to be take care okay this is going to happen ahead like this, so okay I will take care initial itself so when he starts I will take care but there is something, which is non systematic random if they are random what can you do it happens and it can happen any instant of time okay so as I say drift is very important both systematic and random errors are very crucial part of our designs in this course.

I should not keep saying word design because I teach a course on analog VLSI design so I keep that word in my mind in this course we are really not going to design we are actually going to do analysis how to design and not really define future in case you happen to come for master course here I elsewhere you can take that up option course VLSI analog there will actually design that how much it weighs made and what sizing.

How we do that but here I think we are doing more analysis the problem with most silicon chips are that in digital circuit what we do is let us say I want to make a microprocessor so what I do is most companies may have or at least me I may actually have blocks which are pre designed prefabricated pre tested memory block register blocks ALU blocks these are called standard cells the new name for all this is IPS intellectual property.

So each can be designed and hold and do not want tell you you can I give you kind of thing so these IPS are not available in analog because analog is so much varying things or you will have to create huge number of IP millions of them just to keep and maybe one out of that will be used ok so it is impossible to actually create IP is in analogs so every chip or every system has to be designed okay.

That is why there is nothing shortcuts in a row and that is how you have to learn analog seriously because every case is different from the last one then there is a problem in all digital people are looking for 0.8 volt power supply battery 1 point 1 volt say we want to reduce power mobile there is one point, 1 volt battery now they want to reduce to 0.8 maybe 0.6 latter because power dissipation is very crucial for us.

So what we are saying that if you do good for digital which is very good if you digital may still work on 0.6, 0.8, but that is against the whole grain of goodness for analog but since you will always as I said earlier digital will analog will be part of digital you will work on a bad tools and say oh design a great car but tools are you know age old Ambassador card **(FL: From 07:09 to 07:10)** custom tooling hammer a pass but you want a Toyota Corolla to come out it is very difficult.

But, that is what the whole challenge is about therefore analog circuits do be won but not very low power but there is an effort and that is the challenge that how do you reduce the power in even in analog which is otherwise very difficult to get a good performance so these are the issues when we design a chip though these are not relevant for circuit analysis, but just to give where we are so that is the aim we are looking at okay.

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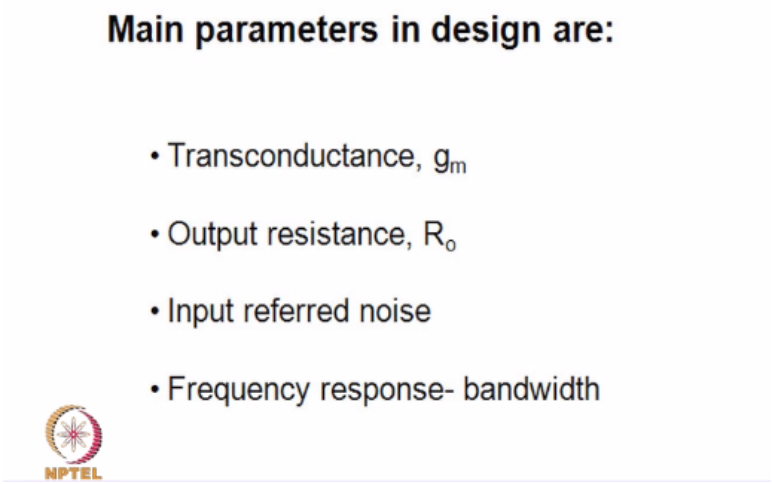

What do I think maybe my English is not correct in that what I say is that it should be able to reject much of the noise okay so that the signal gets amplified but noise does not as much we'll give you some example that if I want to have a two stage amplifier a three stage amplifier and if I pass through this the device itself will add to annoyance it from its own there is an input noise going on now this two noises are now input to the next person amplifier okay.

So it should be tolerant less tyrannical should stop that noise to go ahead this is what I meant if I am not clear in that that is what is that clear so I repeat the three parameters in our analogs are Gm which is trans conductance output resistance which is very important for us and the noise

which means as I say we define as input referred this is a very interesting word in good record noise is seen at the output is that clear and we said no but we you must specify the input what is possible.

So, there is something word will change from output to input and we will say its input and then the finally and the most important parameter in our design or in our circuits is the bandwidth how much frequency response that is let us say I am an amplifier and I want to design an amplifier which will amplify the signal even if the signal frequencies goes to say gigahertz but this statement is very cheap or simple.

Why what is big about having an amplifier which can amplify gigahertz know most amplifiers will not go beyond few mega hundreds of my guards law of effort has to be done if power to amplifier gigahertz so this is called frequency response and associated which I did not say it very specifically and last time I did say something about it there is a gain bandwidth as the product which is relevant to us.

So, if we increase bandwidth your gain will go down so gigahertz you may have a unity gain one gain that means no need kind of or even less than one so not the only solution where gain has to be remained at something I want gain of 20, 100, 200 and that gain I must attain other why amplified if the gain is not there this is in life as well if I put some two hours here I must get a good grade they know some output has to be good.

So, this also is an issue which is interrelated so Gm has something to do with bandwidth Gm has something to wit the gain so we must now look at if I increase Gm what do will happen but if I increase Gm what else will happen which may not allow me to increase the bandwidth or vice versa that is the crucial analysis we like to do.

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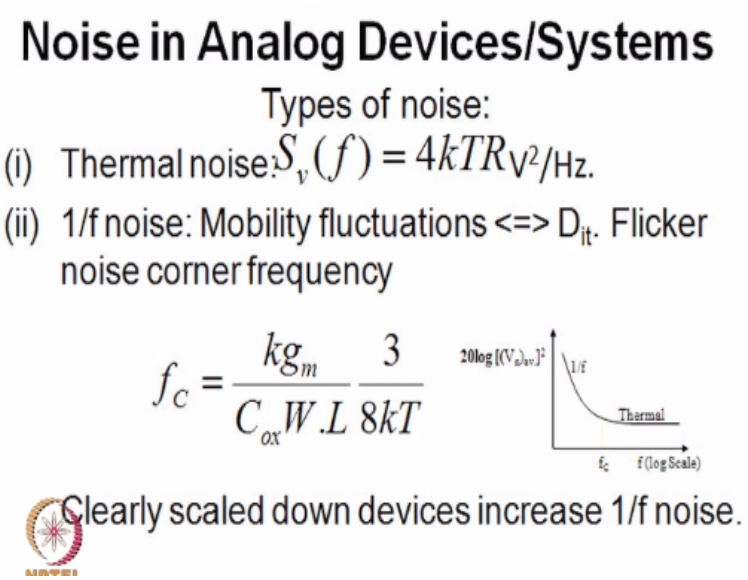

There are different kinds of noises in the system one is called thermal noise and all it is called 1 upon F noise we may not look into details but just to give a figure, which I do not know whether you can see from here the this is log noise plotted this call noise voltage versus frequency do you see here somewhere.

So initially at low frequencies 1 upon F noise dominant is that clearly they figure 1 upon F noise and as the frequency increases it is the thermal noise which takes over thermal noise is essentially because the random motion of electrons and other things in the atom okay atomic system so yeah there is a possibility that some may dominate somewhere some may so this Fc cutoff may be higher or lower in different devices different systems.

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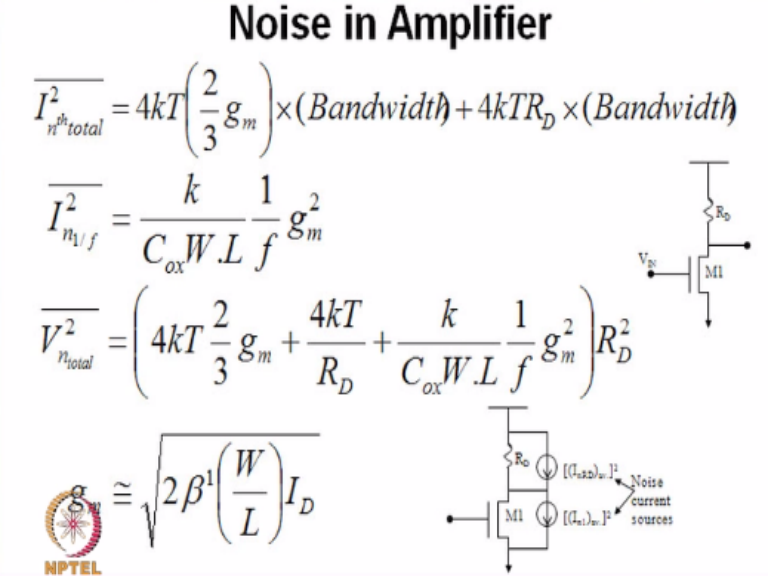

So, there is an issue how to control noise and all analog circuits are worried about this noise at the end of the day I could just forget that it is the trans conductance which if you change will correspond me change the noise itself because the expression shows noise square is proportional to gm squared is that clear now so if I increase gm for gain and bandwidth some way my noise is also increasing is that if you know clear that my noise is what I have worried about okay.

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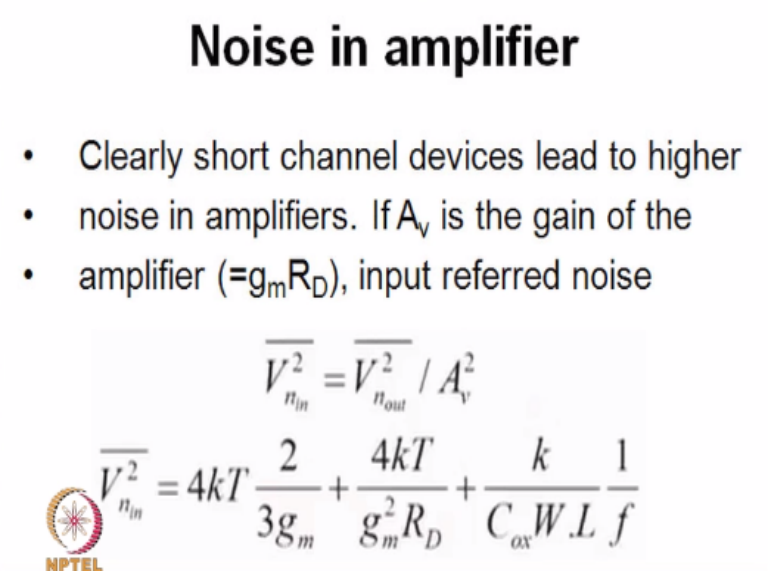

As I said this may not be the major issue for you this course but just to get an idea that we are worried about noise in all of our designs it has to be here this is the word called input referred noise V nm square noise is always expressed as squares A square voltage because it is some way

related to power and therefore it is always expressed in voltages so V in square=V in out squared divided by gain square this is called input refer noise.

The reason why be always referred if you see the expression you need not know anything these are all controllable input parameters and therefore what is the noise essentially will come will be decided from the transistors and the inputs what you are connecting to therefore we always refer noises to the input side by dividing this kind of Av squadrons okay.

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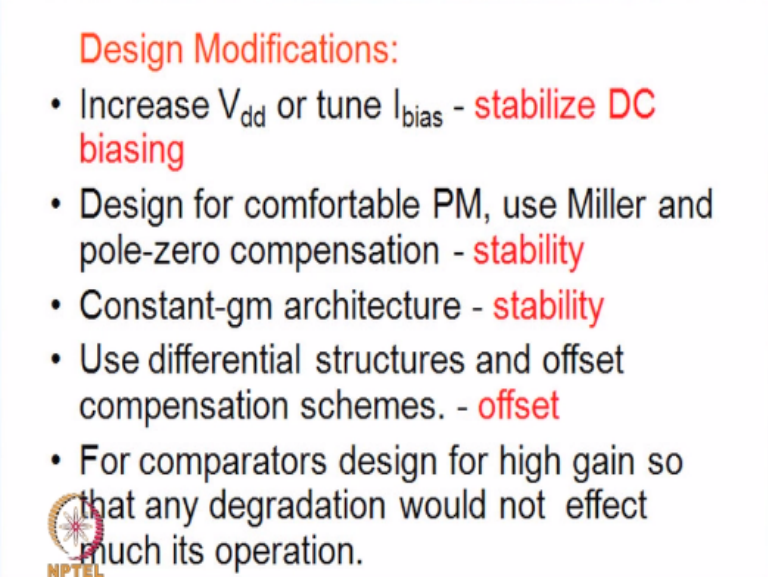

Just to for design something we need to work on higher Vdd if possible or what we call bias current should be stabilized we should also look for what the words are will come back these are very important word in our analog PM what are the PM means phase margins so in analog circuit you can think of phase margin not a great thing if you have a signal V=V0 or VAE to the power something or sine Omega T plus theta plus Phi or what are these and if the signal goes through the system this Phi changes to something else.

Let us say Phi 2, then the margin on phase margin is Phi 2-Phi 1 because the phase had changed now is that clear it is called phase margin so it is very important for us because phase margin means something has now changed not only in the frequency, but also in the phase shifts how come and therefore very crucial in our designs and they are somewhere related to what we call and we look into these transfer functions you are not done control course so far I think so okay.

So maybe I will introduce to you what is pole and 0 if you have done that code then I would say you are a pole 0 (FL: From 14:39 to 14:40) so, this pole 0 we will come to expressions and you know what I am talking they may decide whether system will remain stable what I mean by stable that if I change the frequency or signal strength the gain should be proportional otherwise if it changes then I have worries and that is called stability of the system.

In simple term one may say I am designing an amplifier and if it starts oscillating that means it becomes an oscillator it is an unstable system and this is very simple you can see from your future when we do that when I design a good oscillator it actually dams down and becomes some kind of a damping system it gives you gain and reduce again sushi rolls okay so when you are trying to get a good oscillator that self sustained it does not sustain when I am making an amplifier it is definitely start oscillating.

So, I want the constant gain constant signal and it is changing now so there is a design that when I am designing amplifier it should not oscillate and when I am designing aside it should not done should not amplify use and then down now so these are the two complementary contradictory terms which is word goes into words stable stability if it is an amplified should they be in amplifier if it is a oscillator it should remain oscillator to do this we say constant gm kind of circuits is better there are many methods.

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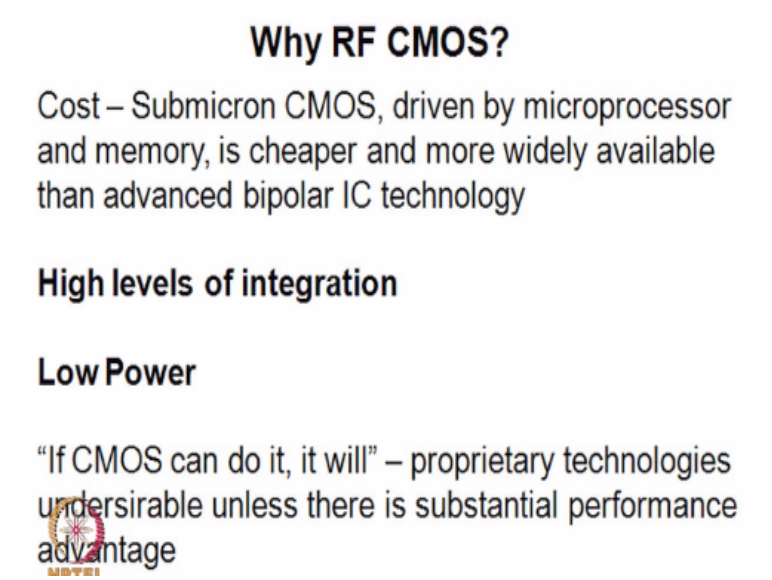

We will see if time permitting and the other issues are upsets as I already said the drifts can occur and how to take care of upsets okay the another issue which I thought you should know which may not be directly related to our course, but for this lecture I may tell you there is a another analog or the analog come digital system which is becoming most important as far as the money part in the silicon industries which is called RF signals.

Why it is called money spinner because all of you barring exception may be holding a mobile may be holding more than one mobile, if I give you 2G now you want 3G when we 3G networking start you have 4G you want everything on your mobile now mobile works at different ways one is called GSM the other is CDMA mean you will see that in your communication courses letter so either of this system with your do you have a frequency ranges, which is around gigahertz these ranges are called radio frequencies.

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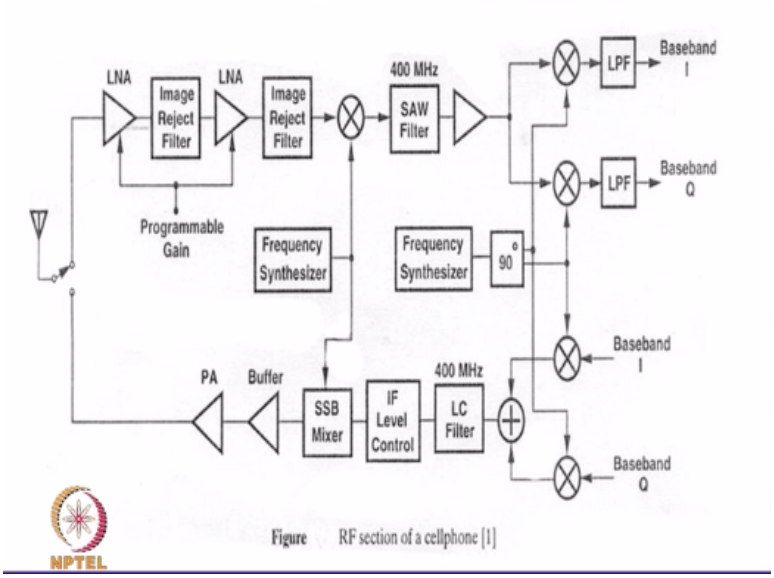

Figure RF section of a cellphone [1]

Since signals your voice is still analog much of the inputs you will create are analog these chips are called our systems are called mixed signal there will be analog blocks and there will be digital blocks so the RF which we are now creating which is what we are really looking for nowadays this is something like a typical mobile system can have a look at it okay this is my antenna this upper part is receiver the lower part is transmitter okay.

So we start with first part which you see here is the low noise amplifier this is analog low noise ample why it is low noise because the signal which we received from antenna is very very weak last time I said that strength depends on how far you are away from the tower and many times it is called fade out you will not even have the signal okay this is why you need to boost that is the first amplifier which we put is amplifier do noise on the interest part in this is because it is an amplifier it will have a bandwidth issues.

Which we will see later there will be a filter has to be created which will reject the frequencies which are not required from the signal these are called images it filters this is also analog block you may need another amplification at the after rejection of those frequencies because initial gains will be smaller but the next gain should be higher and these program will gain miss their gains can be modified then we put another image reject filter because you have a bandwidth if you created in any and then we go to what we called mixers.

Which are partially analog partially digital and then we put a filter then you another IF amplify this call in image we have created intermediate frequencies after mixer let us say we are gigahertz or you may go to few megahertz 100 of megahertz 200 of megahertz and maybe sometimes they may have more than one mixer to get a lower frequency which is called baseband okay.

You may have this is what I shown you here this is another mixer another filter and your base plants this is called receiver part okay beyond this base is once I receive will convert to digital and further processing everything will be on DSP and then if you really want to see some displays or something you may convert the digital data output to analog we do it so two more blocks which are not shown is A to D converters and finally D to A converters but basic processing major will be done in digital.

So, a trans receiver this is called transceiver Y transceiver is y transmitter and receiver to be if you are transmitting your bass lines are here this is called orthogonal system shown here baseband 1 and baseband Q okay, two mixers than you mix do a adder which is also analog adder filter IF control single sideband mixer these are two major amplifiers which are again power amplifiers and a buffer which are essentially analog blocks the power amplifier must have sufficient power.

So that from the antenna I can transmit for a longer length so this is a typical cell phone structure it is not clear we may be not interested beyond baseband in this course because we are not looking for digital part we are looking only for analog part so we are so one can see all that time what I am talking about in analog I am looking for amplifier makes us maybe one for mixer you actually require a frequency source which is called a tone frequency synthesizer or also called voltage controlled oscillators.

Now this V shades on an analog block okay, which is given to a mixer so you have how much what you are going to do actually in analog and amplify different kinds different bandwidths different noises you need oscillators okay for different frequency synthesized mean different

frequencies can be created you need filters you pass high pass and pass band reject all kinds of filters these are essential blocks in analog no more notice what is the ISDN anyone heard okay.

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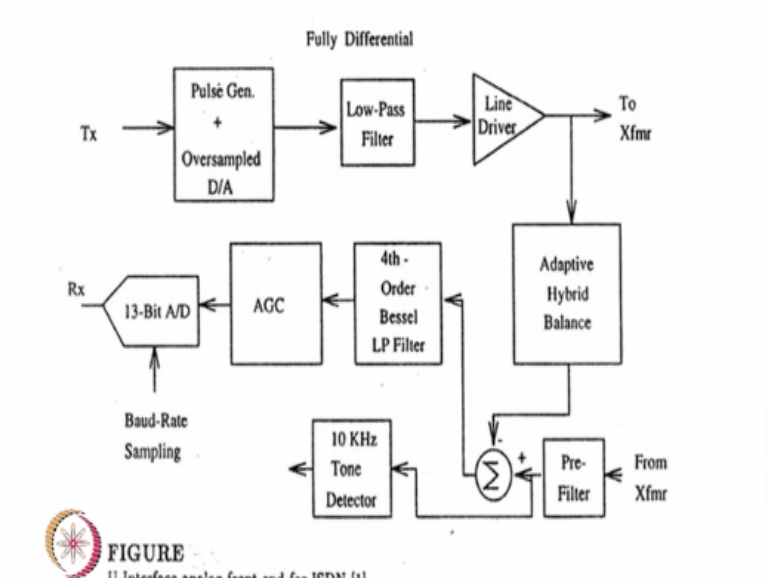

S stand for Ward D stand for these of course digital and is network integrated services Digital Network is ISDN which is our BSNL or MTNL allows to have all food that is data transmission, video transmission, computer connection and really all can be fax all can be or even earlier telex service to call all services can be given on a single line by switches it is called ISDN this is the network kind of circuits which is ISDN will provide for you.

So again you can see there will be D to A converters file generator filters, line drivers, balancers pre-filters and tone detectors all these are basically analog blocks partly converted from D to A digital to analog and now you do processing on analog part okay so this is ISDN is replaced already by what cable modem cable itself can do all the jobs wireless can do all the job lands are come W lands Wi-Fi WiMAX.

But what is the problem with what was the good thing in ISDN because it was on your telephone line which in old days you will not believe it your parents may tell to get a telephone in Mumbai as late as 80's for the nightmare to register and after eight months one year or two years depends on if you know someone or you do not you may get your line so getting an ISDN was for an

institute more than achievement in eighties when I has to run ISDN director of mine was thanked that is what effective.

Now we are changed so much you do not realize but there were the time when we actually worked on such poor systems okay.

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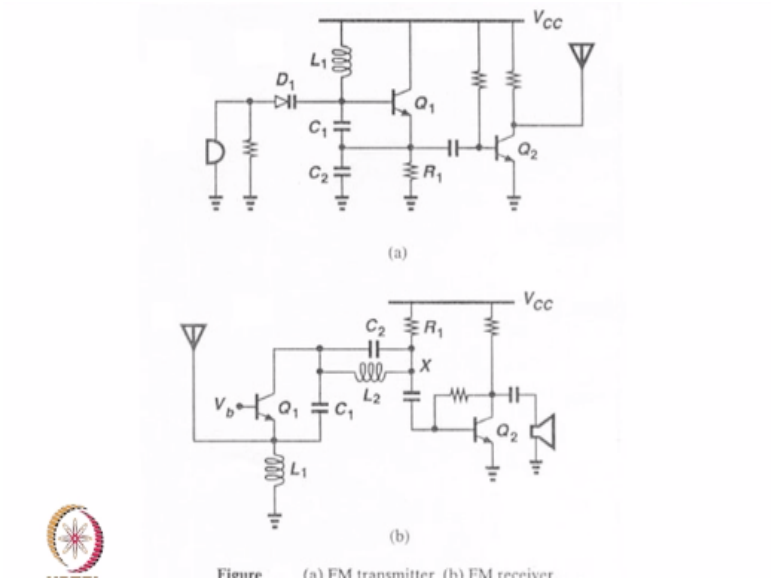

Figure (a) FM transmitter, (b) FM receiver

These are essentially circuits which are called frequency modulated transmitters and they see whether you can see there are this is shown intentionally bipolar because these are old circuits you require inductances, capacitances, resistances, transistors here different unstressed sizes all this and of course you can have a loudspeaker you can have microphone and this was our old system but basic even now has not changed because you cannot change the basic operation of an amplifier or in anything.

So even if we are done much more work to simplify it or reduce the components the basic idea of analog circuit design is still same as 50 years ago.

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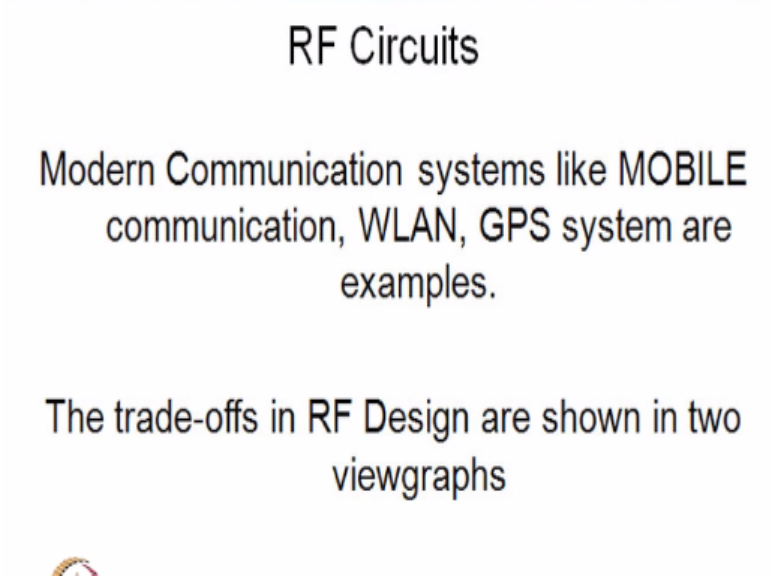

We were doing this like mobile WLAN and GPS are examples of RF the trade-off in our why RF design I am showing you for your sake in the case of digital I did not show you very much but I showed you that there is a there is a triangle of design or what we call trade-offs what are the three things last time I showed you I said I do not know whether I have shown that figure if not I will again show you this is let us say power this is speed this is how we call area of the chip what on this area.

So if I want to reduce power then I will reduce speed but I may actually increase or if I want same speed then I may increase the area so triangle has to be pulled up or pull down but the wall net area will remain same in the technology so you cannot achieve all goodness because of the triangle limitation.

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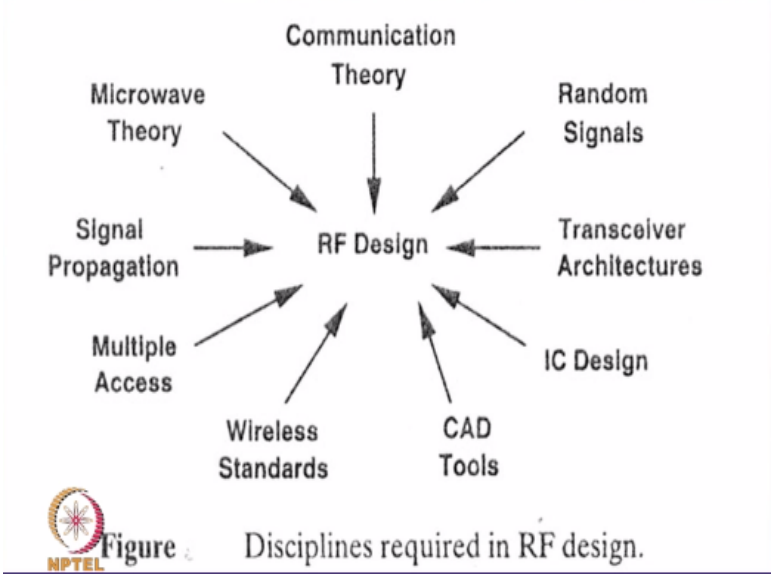

Figure Disciplines required in RF design.

But if you see RF this is the problem how many things we control there three and how many now I am controlling almost hexagons six of them maybe a better figure can be here.

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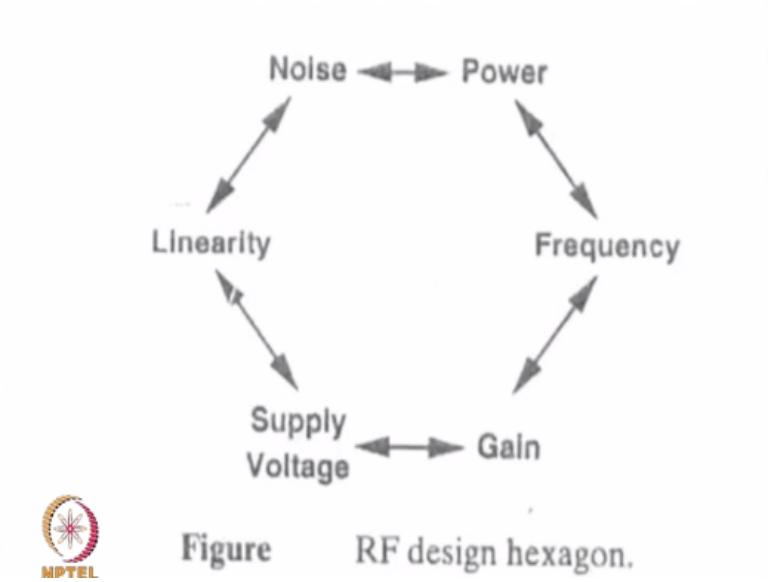

Figure RF design hexagon.

You have a linearity power supply value you have gain frequency that is the bandwidth your power and your noise and now you control one the other is going to be affected, so when I start designing an analog block I am worried of a particular direct there is okay this is 0.8 volt mobile cannot get more than that supply oh that means now I have reduced this I do not enough currents oh so how much gain I can get try to do increase gain by size or mainly lower than frequency because capacitance, I want okay.

Then must push power that means I must increase currents if I increase current I will increase noise so I have to keep worrying now that how do I optimize most of it okay but you cannot achieve all of it is that clear to you why these limits have been shown that do not tell me that zero volt infinite gain infinite frequency 100% linear zero noise zero power is achievable this is not done okay.

If you want something from me you must give me something that is the world that is how world works is hot labels are they system is simple so in our designs that is what the designer job is to optimize the best of it and say okay this is not a chill but this I can do so you cannot have everything but okay if this is your more important parameters okay.

I will control them but they have the cost of other three or four so someone has to optimize this and that is why do the engineers are required is that clear why what is the issue I am raising all this I am trying to tell you that automation is always possible in digital many ways because there are few parameters to control.

In analog RF designs they are too many to control and manual intervention is essential because every person will come with some other requirement and it is oh my god no how do I achieve this so your design approach or your analysis approach should be very good because you have to meet someone's specs which will be different from your next circuit that is why the analog circuit essentially is slightly difficult.

Some may say but more interesting because otherwise there is no this is required and we keep saying digital people and you do not need this you do it automation you give something that will give you finally at the end of the day computer scientists make as good a chip as the electrical engineers okay, why because there is so much software available.

You can take download many things and start designing and chip may work as well because someone has already standardized that and can be used analog there is nothing something every minute I need myself to see what going on therefore please remember that why analog RF designs are important or difficult is because of its requirements.

The major problem which I said you is in Wireless application which are the major applications why is a major (FL: From 29:24 to 29:25) app sub load mobile use carrying a VLSI or silicon community are both hanging parents now then they may not like that but I say VLSI engineers oh thank god use two of them Ipod to be thorough so industry is actually working on wireless systems now okay which is more money spinner than anything.

So we are the other systems like bluetooth, WLAN, set-top box you must have seen nowadays almost everyone you are DIRECTV home DTH this is essentially you have a box there which actually picks up a frequency of your choice and does the set of words set-top box why it was called top it is put on something set-top box then there is intermediate frequency and baseband part of radios.

There is a radio which has come which is called software radio think of it what I said software it is anything different nothing with radio per se that is the radio receiver but the word is software.
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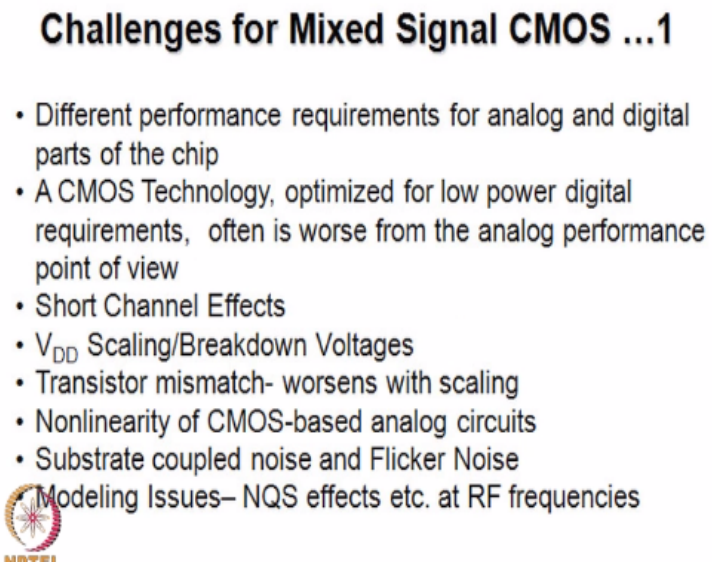

There are many challenges in mixed signal and why CMOS why did I say last time because that is the technology digital people will force on you there I like and I do not like is not my choice of analog say (FL: From 30:46 to 30:47) arrived about bipolar blue but that does not work they say

this is the technology now it is what is the kind of technology we are working on CMOS for digital chips 28 nanometer.

That is the channel length is of the order of I started working in 70's when we worked on 50 micron channel length device in my 35, 40 years of time now the devices have reached channel length of 28 nanometers to Edina Armstrong and sooner we may actually reach 11 nanometers in few years first we go for 16 and then maybe 22, 16, and 11 things go all well zero.

So that is the technology but another people will she let her longer the channel link he is very happy he said thanks okay, my gains are good my bandwidths are good okay, but digital say but 28 nanometers that is what Intel has come with all new microprocessors 20 anonymous so the problem you got the point the problem is bad tools for us good for digital, but then you work for those for this technology is why it is called mixed signal design it is tougher and pure analog why because pure analog.

I may use bipolar why you boss I have better choice but if I had to work in the money making chips which is wireless as of now for example then I have to go for what digital people would say and that is what we are doing right now if you are shrink the device there are many other problems like short channel effects there is a problem of breakdown problems there is a non-linearity problems that it is couple of noise problems there is a huge flicker noise I adding now okay.

So point I am trying to say that there is what is this increase in device code any time you heard the word in the devices if I apply something the response can you know for example if I change bias the device does not respond instantaneously now you just change the bias external internal it takes time you know there is some issues going on but in system what do you want we want a quasi if you want a steady state.

So we may not get a real steady state we get a steady state which you call quasi steady state but in very low friction circuits or low channel devices this it is un quasi static steady state is not positive non steady quasi static now how to model something like this, which is non positive this

is a major issue in modeling in the case of sub hundred and sub 30 nanometer devices to get quasi we modeled we say okay.

(FL: From 33:50 to 33:51) they are equally the steady-state had time on our we have inning, so what do you do that is a you at RF frequencies ready so it is not possible all our do you solve the continuity equation you say studies field there are say I outdoor training class really now, if I do not apply a continuity equation for device how do I get the relationship between currents and the fields poisonous equation cannot be because I cannot get now doping exactly.

So I cannot put in field a field equation so quasi steady state was assumed in most devices but when I go to a lower channel devices this is modern so this course has nothing do with it I just want to tell you why we are worried because they are telling means I am now talking myself analog man when I sit on digital I tell those otherwise people, so digital people forcing us to think much more now because they are moving in one direction which we do not want to go but we will have to go kind of thing.

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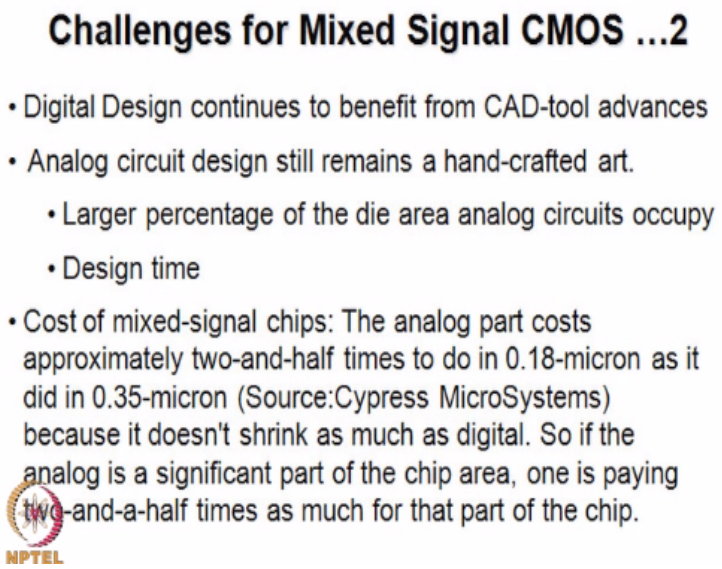

This is what I said digital design is getting so much computer aided design tools their designs are not very difficult okay analog circuit still remains a handcrafted art and that is what the word I you say every year it is a art so it is called art of electronics it is not art of designing it is an art of say artists it is not even science so all cannot become a good analog designers you know all

cannot become artists I may actually penned by putting some brush here there but it does not say mix it but normally usually what we understand painting.

So say crafted art how good you are analog designer is individual and that much how much depth internally you create for yourself a larger percent of die area analog it is much easier if larger area is given but they will give very small area to that is an issue probably with 100 percent area **(FL: From 35:43 to 35:45)** I am a posh person in a lot of us may sub go so that no worrying us in every way then the design time it takes very high because individual blocks have to be designed time means what money.

So many in design engineers will be working so much money it is so much money so an area of the lines normally being smaller even than they take larger design times because they need to meet very stringent specs okay cost to make signal chips and analog two and half times that is what let us say in a 0.18 micron as did in 0.35 because it does not shrink as digital everything you know like scaled.

(FL: From 36:33 to 36:45) thing point five half 0.25, KO point one nothing happens in analog like that okay so that cost never reduces it actually increases if you go further so it is worrying that that analog blocks are costlier than digital blocks as you are shrinking okay because you will require more effort down to design on that okay.

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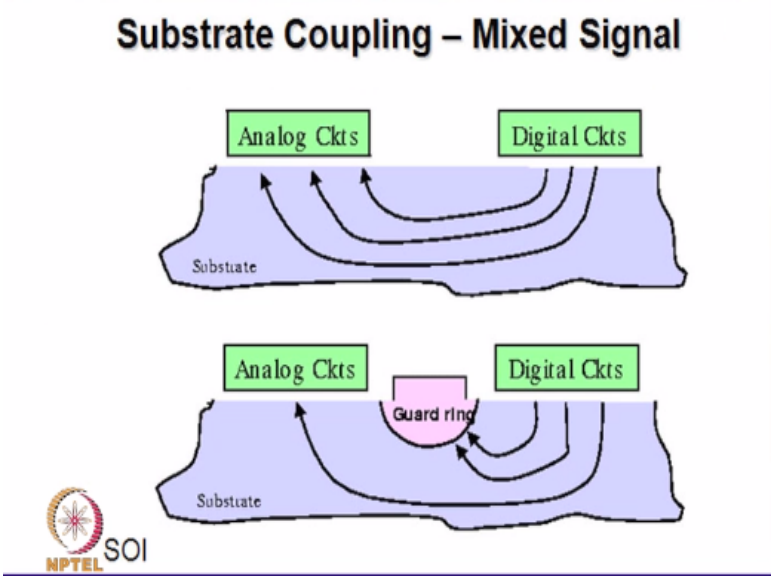

Another problem and make signal is since you are both digital and analog on the same silicon they are connected internally in the suspect so what is good maybe good but what is not it may actually create problem for the other okay particularly digital switches do you understand what is digital one zero one zero and higher the frequency it will do even faster that change will apply to the bias at the substrate that will become signal to analog noise okay.

So this inbuilt noise creation from the digital is constantly through software picked analog and he is worried obviously, has forgot that is why I say, why I say analog particularly in the present it is becoming difficult is this okay just more interesting figures.

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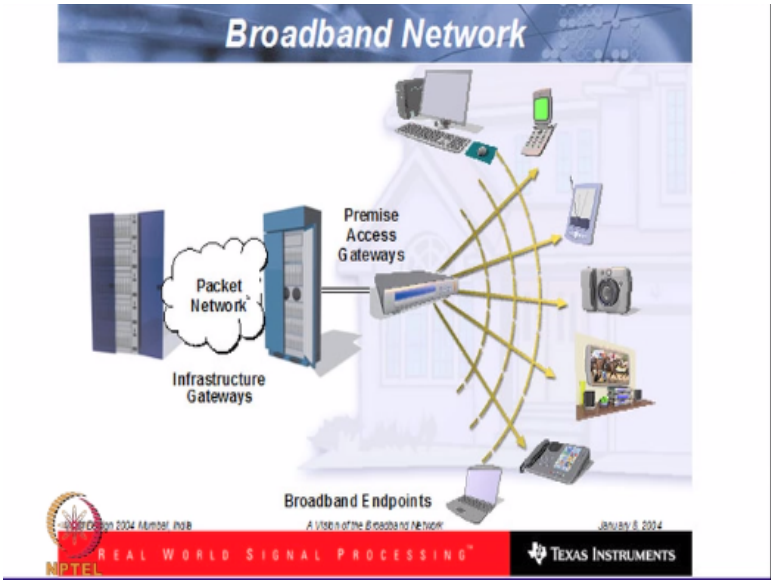

Nothing great now in theory this is a very standard broadband network okay you start with a packet networks infrastructure gateways maybe will show you this is your prime axis gateway which is connected to so many applications camera, iPod and this is your mobile this is desktop this is a TV this is your fax machines and telephones and this is your laptops.

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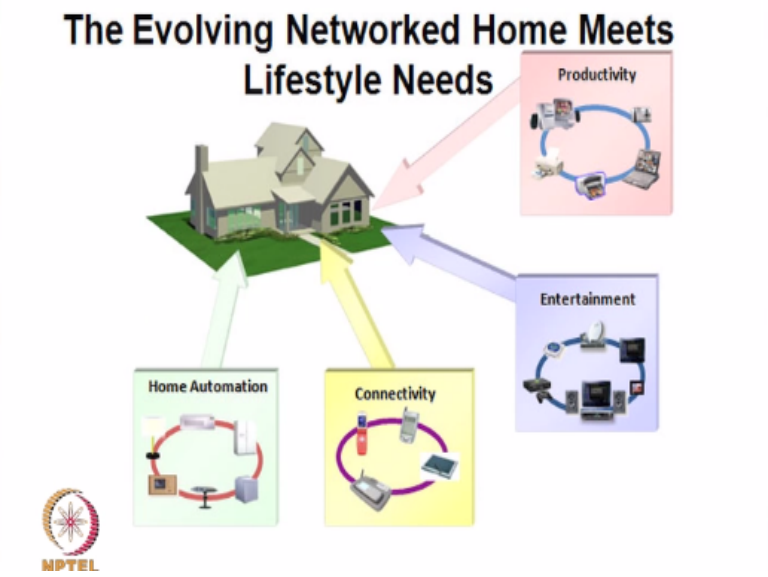

So everything is connected through a broadband so then you will see figures so that is the lifestyle you all want to be you want to sit in your house work somewhere else and you want to do everything almost by click of your tip should happen okay this is possible this is possible that is what you all want and this may happen soon and most people are already working on it in many countries like for example in many European countries or in US even in India.

Now your pressure cooker or what is called electric cooker you know the person can switch on at a given time and after some time switches of washing machine may start after some time and switches off kind of thing sitting at the Fagin when you are working okay let us say your ladies who work also now it is by the other sex very good 50% is a large number 33% they were asking now already 50% okay.

In most silicon industry this is a cable network what is cable network all of you those who are does not have this Zee or big TV, DTH home still may have a cable coming from your cable operator which is 4 gigahertz line which is hanging around the road hanging around everywhere

finally reaching your home even that can be connected through that you can actually do most of the connections now.

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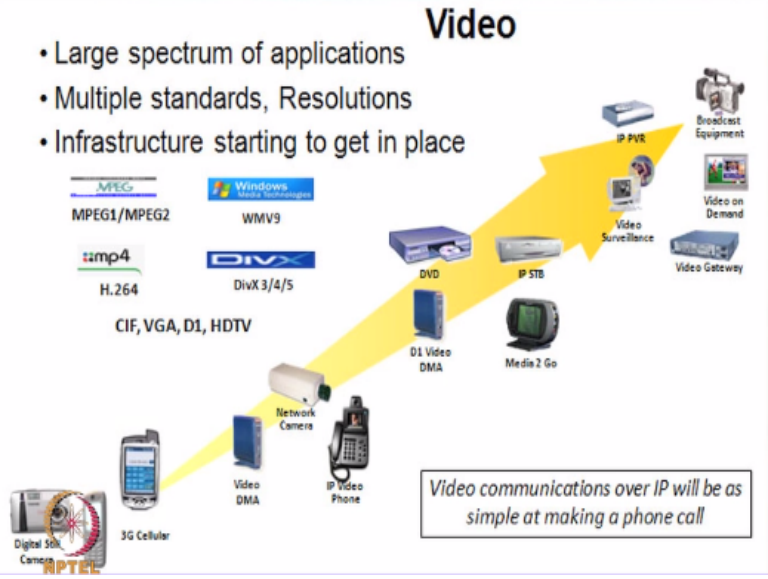

You look at the video where both analog digital are required a camera, cellular video DME what is DME a network, camera, IP, video, DVDs, D1V, IPS, TVs media, video surveillance, video on-demand broadcast everything right now what you see as both analog and digital dominance.

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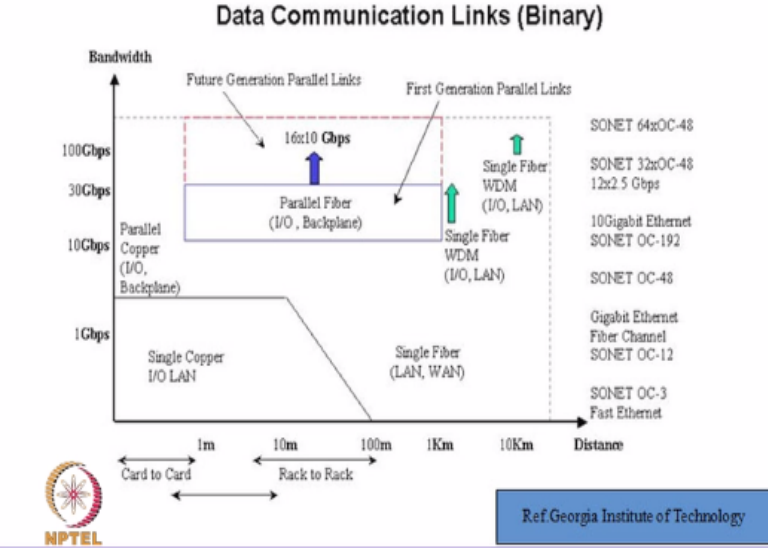

This is the fiber links we are looking for bandwidths of the typically around 100 gigabits per second which is soon at 64 OC 48 circuits and you may go for multi fiber multimode and may

increase further the transmissions well ultimate aim that repeater should not go beyond before hundred kilometers is what we are looking for right now every 3.5 kilometer.

There is a repeater for optical fiber some new fiber lines have up to 10 kilometers but most have 5 kilometers early it used to be one kilometer what is the problem if it breaks we will have to remove that link splice it reach welded put another transmitter seen here that is the issue now we are increasing that to 10 kilometers that is what we are looking for.

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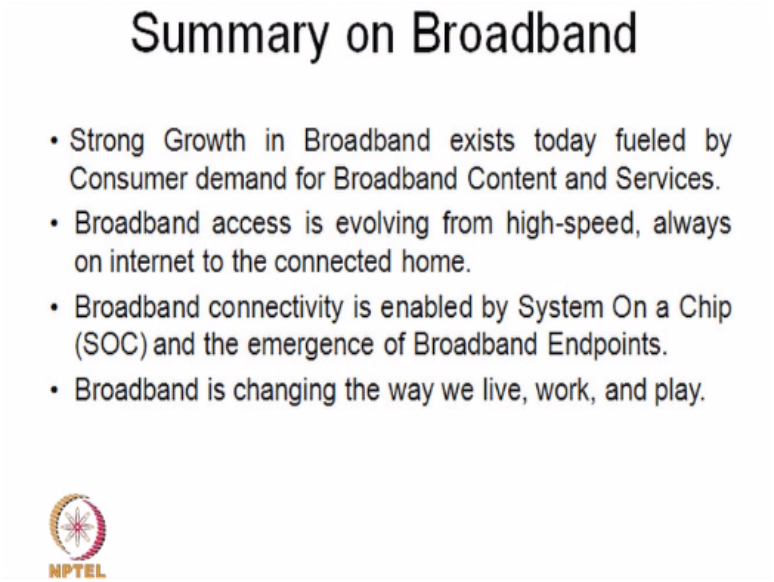

Now broadband is going to grow fueled by consumer demand broadband access is evolving high speed because you live want an Internet very high-speed Internet that is why broadband is being pushed very heavily okay.

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3 Crises in VLSI Design

- Power crisis
- Interconnection crisis
- Complexity crisis

We will move there are three problems in integrated circuits the first problem is power we want to reduce it the second is interconnect how much length I said in Pentium 4 first Pentium 1, 1 kilometers and the present Pentium or the neon which has come had 3.6 kilometer length of antennas so on a smaller chip up to centimeter by 2 centimeter you get the point it is the perimeter how many times you go like this that is the length the length of the chip is no more than two centimeters.

So do not (FL: From 42:23 to 42:24) think that - Thank You meter micrometer, so that is our major worry because if something is going that far my signal will attenuate by the time it will chase you think few millimeters so much capacitance on the line it will just RC time constant (FL: From 42:42 to 42:43)Gotham juice caboose card number days boosts Kia the phase, phase margin In phase margin I got a clock (FL: From 42:53 to 42:54)X signal booster o'clock to 3 o'clock we may face many phasor number 8.

So there are issues which are called interconnect issues then of course complexity number of sub devices transistors are reaching millions 42 million tons stood in Pentium 4 ah sorry Pentium 4 first one Pentium 1 now we are going for 800 million transistors normally for which is 142 million the present circuits can go up to 850 million transistors that clear so that is the complexity we are handling power crisis.

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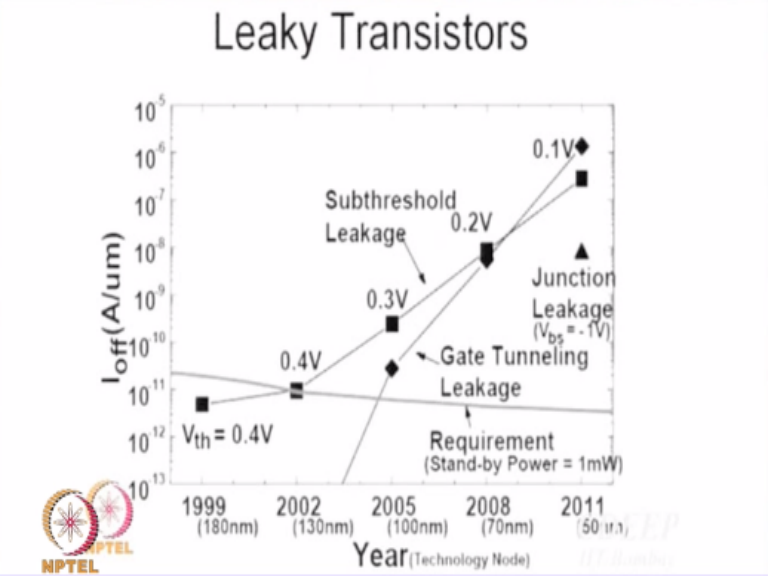

The major worry in power has come because of the devices becoming smaller there is something what we call leakage problems in earlier time this word never came to our mind okay off current off current means when I my for a digital for example when the input is zero or lower level no current passes in the circuit we see that is what I switched off with it but we are shown that time that the on current when it is turned on is much larger compared to off currents 1 million.

And this maybe non on but if that one million has become now hundreds of tens of microns, this has increased from nano amps to tensile nano we are closer by okay even if 50 percent of the circuit is off and there are 100 million transistors let us say 50 million inverters on that half of them are off 25 million into this off current is not a small power which you thought of earlier zero since the complexity has increased the off current itself has increased and on current has not increased very much in fact they have decreased because of power requirement.

So now this is a major issue circuit start failing because of the off current okay the joke is if you work on 28 nanometers 66% of the power is off power and 33% or 34% in the on power that means if you keep your mobile on it will consume 34 percent of the power if you put it in standby it will actually drain your battery more that is why I do not discourage you constantly talking on mobile because at least net energy of the world is saved because battery is not getting drained okay is that clear okay.

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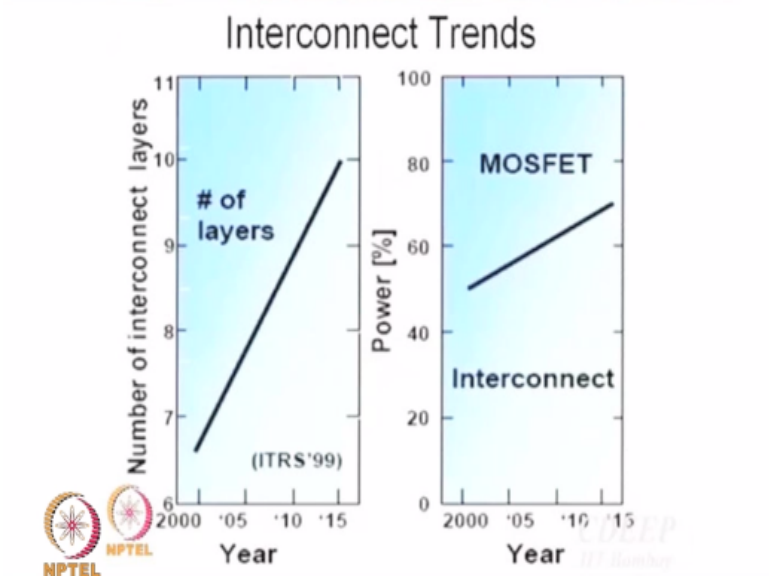

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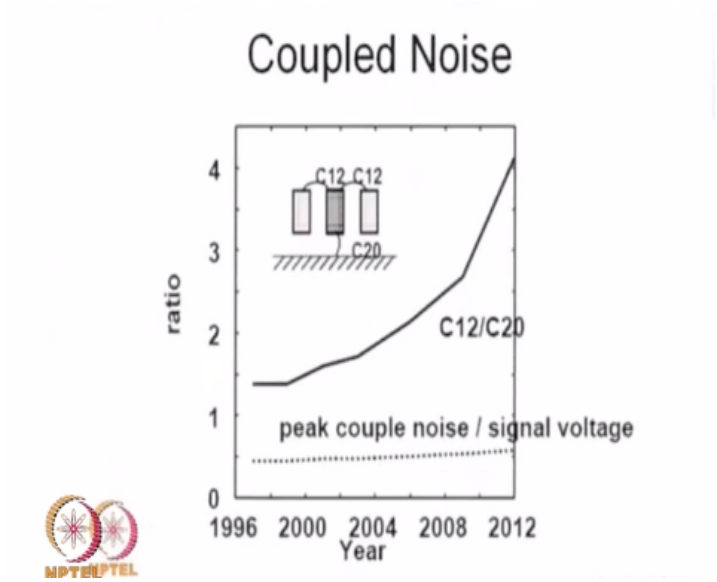

As I say number of interconnects are increasing normally it is a noise issue there is a another issue had come to transfer to interconnect lines interconnect sitting interconnect with a metal layer metal sitting on some insulator they saw interconnect runs but this is like a net like an RC circuit which means like a transmission line okay.

Now when the two transmission line come closer they have a capacitance in between as shown here these are two metal lines three metal lines and there come closer epsilon a/d d smaller a couple so signal passing in one line may actually get coupled to either side okay this is called crosstalk as I said last time so a fish string reduce everything close, closer, closer fish will kill

you okay so interconnect it should start very, very interesting because they pick up too much noise in all this work.

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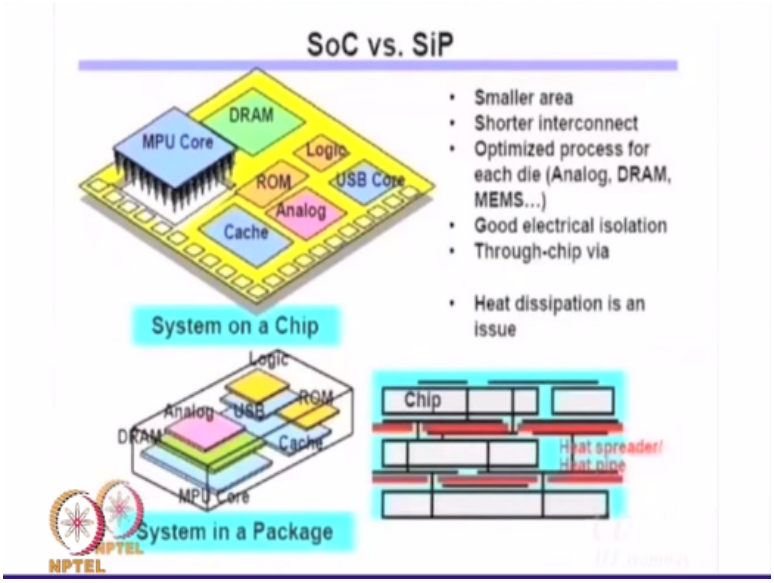

Finally as I take the number of transistors are increasing number of kinds of circuits we are increasing the board has becoming very big and to maintain their connectivity proper is becoming a very important to design such a large system is very difficult so we design blocks and try to put on a one common platform which is called system on chip this is the current trend system on chip SOC there is also another game being tried by Japan and some other companies just call system inside package SiP okay.

That means you are number of chips put inside one package it is called system in package this particular has 28 chips Sony camcorder has this chip which is the DSP memory many things there are four layers seven chips on per layer 28 chips package one single package this is called system in package or system inside a package.

Where the other one is like which we call system on chip or SoC where each block is given an area where they are mounted on a single vapor or single area it is called system on chip these are possible mechanism which we may work here it may actually get analog it may get digital it may get MEMS it may get all kinds of circuits can be separately connected properly so that you may design in large systems this is what again we are looking for your times this is 2014.

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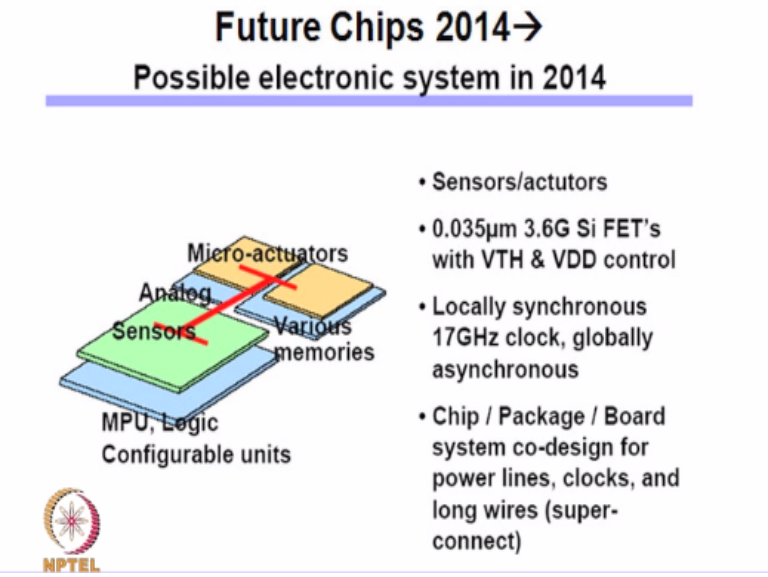

We are going to work on 3.6 G will require for strong control on VTH we are working for 35 nanometer already crossed okay forget that number now 17 gigahertz plot we want to run how much clock we are running in microprocessor which you use PC 3.4 gigahertz we are looking for 17 gigahertz chips now okay this will be a greatest thing to happen soon okay.

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This is what the world is looking into 10 meter wide road designing a map of 10 meter wide road for a world atlas is what essentially VLSI design.

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I just give you the last few slides I do not know because many of you are not even born in 70s there used to be a famous LA in LA there is a famous serial based on some secret agent called Dick Tracy this name was Columbus and he used to have of course here if you are even at your age you could have seen some of 007 Bond films he makes a lot of tricks on those they were only film.

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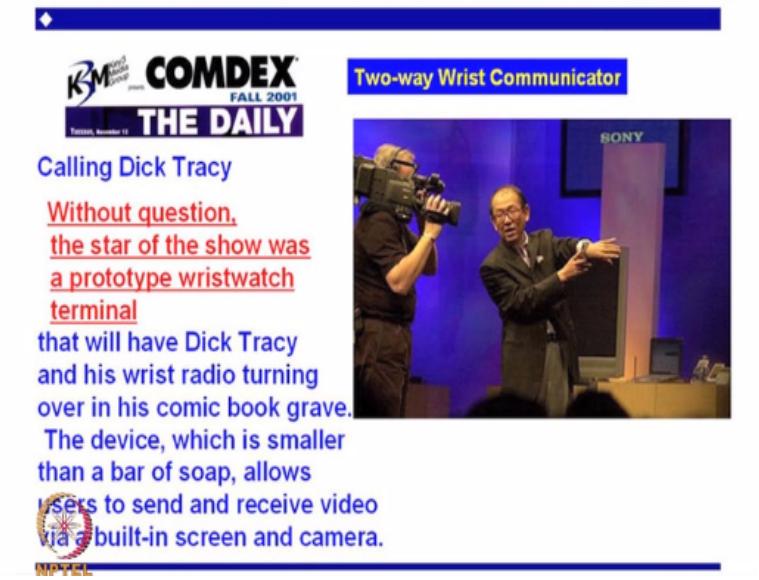

Those days all that what was they were showing then like here the camera here the music everything on his watch in 1976 serial they showed this okay Dick Tracy. In 1998 or 97 Sony came out with a watch which this not only what Dick Tracy was showing in 70s, but does much more than what Dick Tracy could do okay that is the progress individual kids are done.

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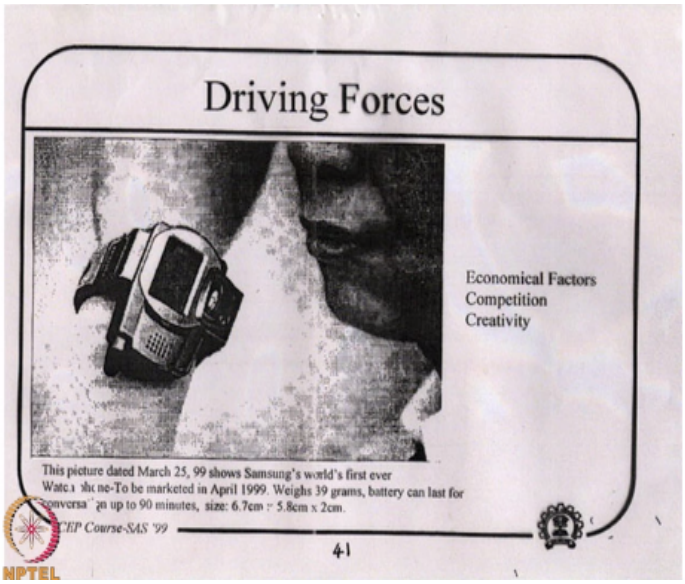

Similar thing came from Samsung, which has a similar watch which has a camera which has a mobile which has watch has watch is also there many other things (FL: From 50:16 to 50:17) yah-yah-yah Kia of course we are also part so many times we are invited for tea in the evening by some family and other than tea everything is served so if they watch behaves well.

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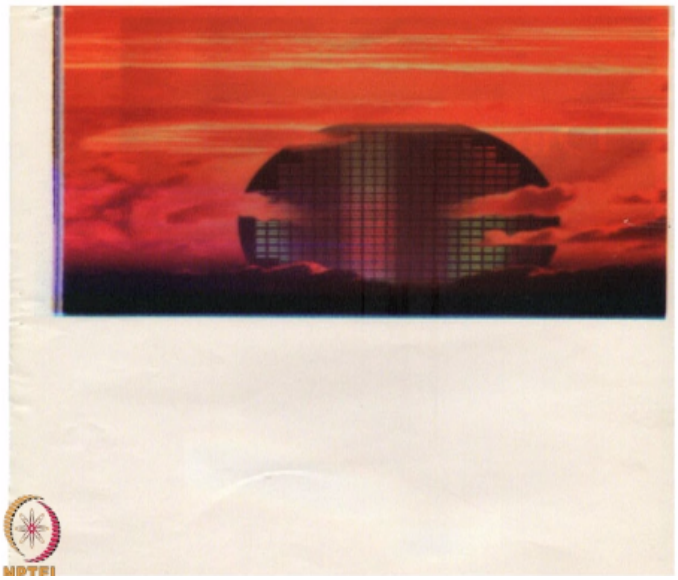

For silicon people this is very important these are actually a silicon vapor with this each of the chip now it is at the horizon okay now if this gentleman is a optimist he will say like a sun this is coming out still the full blown has to come but let us not put mean someone maybe are pessimists oh it is now shrinking and it go down it will now finish it off depends on what you are and what you want to think silicon is going to stand till 1950 come you have career if you join silicon.

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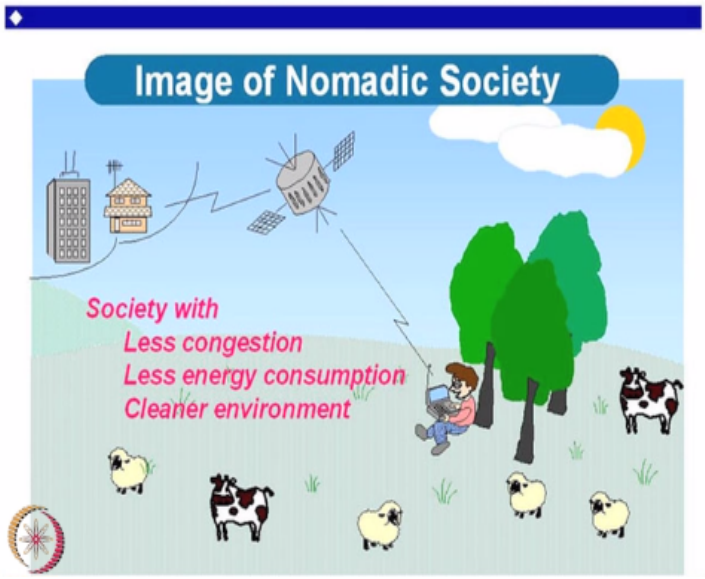

This is what all of us wish Jairam Ramesh wants us to do like this by the way Jairam Ramesh is distinguished alumina of this institution from the civil engineering department I do not know how civil is connected to environment but Public Health is one of their a part of civil this is

called no Vedic society nomads move from one place to the other and they do not stick to a place okay.

So if you in a modern era this is possible you can have all kinds of a small laptop or some kind of a curve which has every control what you want you can live in a jungle or you can live anywhere your office may be far away in a distant city of 3,000 miles or whatever distance you think from good environment around nature everything and you are still working for that company or your home or anything this is what is possible in a very near future.

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"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

Finally before we quit on this is for those who do not want to remain engineers this is my advice executives might make the final decisions all managers do that about what would be produced but engineers would provide most of the ideas for new products manager do not get idea they only manage but engineers get ideas after all in years where the people who really knew the state of the art and who are therefore best equipped for prophecy changes in this technology.

So if you really want to remain in rest of your minds continue to remain engineers one of my 84 graduate then of chorded masters also in computer science not with our department Manish Mandai. Dr. Manish Mandai he is the director of Texas Instrument Bangalore and he is the only Texas Instrument fellow in whole Asia TI allows any academic excellence which has contributed TI is progress a honor which is academic honor called fellow.

So here he is the only Asian fellow TI has a work in Japan, Korea, China, Singapore even in country like Sri Lanka was smaller this Iran, Iraq quote now they are close most of it okay Turkey occurred turkey may not like to be collision but Turkey all these countries and Russia so all these countries only fellow is my student management why because he chose not to become manager but still start continued to work for the progress of science.

He has had some 65 pendants and 3 of his pendants have got the best of Arts therefore he is called director of Technology and he, he does not report to the MD of the company he he starts his own projects and of course approvals up rules are required in the last but he does not have to report to anyone that is his strength.

So if you really want to remain in engineering discipline you have a good example from ITB you can still reach the best and still remain as active in economics as you wish to be many of the speedy shown to you are taken from Sony corporations PPT given to me by Sony's vice president many of the there is a standard book by Professor Razavi on analog circuit there is a video company called cadence.

Some of the slides have indium actually in India there is not a single VLSI company which does not have a ITB students both graduates dual degree as well as postgraduate and since I been here too long most of them by for studied like you have been forced to study with me they had to study go through me and if they are doing analog VLSI or digitally whether they have mustard on my course.

So I say I control Bangalore and Hyderabad so most company if you see these students come here come to and give lecture sometimes user this is latest that is why I get the latest PBT is because of people like you who some of you still want to remember there are many websites on VLSI available on that there is a book on digital circuit by Raybay which is very good book for digital.

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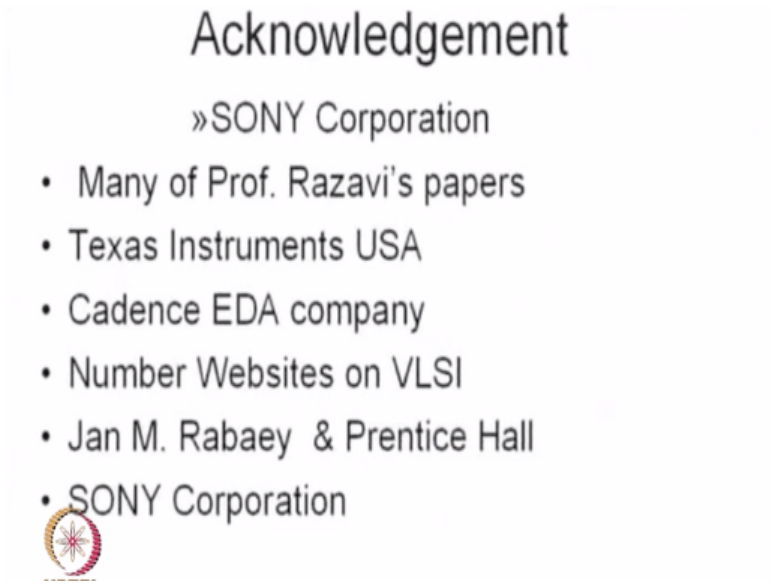

So that is one from there of course and finally thank you for yourself so let us this is I hope that will just introduce few things and then stop by now you must have understood why I showed you all this for two days and I wanted to make a distinction for you that you know all other jobs are as good at the end of the day you want to be happy maybe good prosperous have happiness in everything you want three cars everything is fine.

But the job satisfaction is the first thing you must look for because at the end of the day if you are very not unhappy on your job nothing will be as good as you think you may provide everything to your family but you still will not be happy so at the end of the day if you are happy with the banking dwelling money here they are writing up report fair enough nothing absurd or nothing wrong but all need not do that job okay.

Some should do engineering and be happy if you are learn and if you want to do good and be happy learn what engineering is all about that is why we are actually showing you what is in future what was in past and what is going on okay so that you can correlate yourself where you can probable if it may be unfit as I said we will for next ten minutes will quickly go through some of the issues of analog again analog circuits can be implemented and to technologies.

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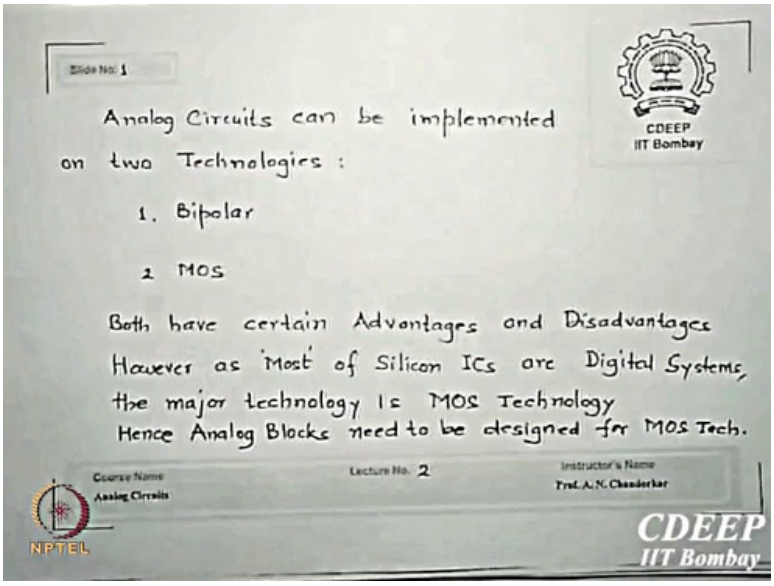

As I said one of course is Bipolar yeah there is MOS as I said earlier also Bipolar technologies are not out there are many chips still in bipolar available in market therefore cannot say one should not learn secondly why I still want to do Bipolar because it is called pedagogy that is how we started (FL: From 58:06 to 58:06) Mira somehow my Mosfet lenita I learned vacuum tubes and I did not have n transistors.

You probably do not know what is that him maybe use 6 to 8 inch kind of glass tubes inside grid plate cathode like at CRT we have to have tubes 300 watt supply DC okay that is how we learn electronics things are changed so bipolar is still not out7, 4, 1 many of the opens are still on bipolar however major technology as I said in MOS.

So we will concentrate also on MOS designs because that is what is now going on okay both certainly I have some advantages and some disadvantages and depends on the system requirement one may choose go on fully bipolar or fully MOS because the most cig systems in marketed are mixed signal they are mostly on MOS so we will like to see what happens if analog is put on in digital technology.

(Video Starts: 00:59:20)

That is why the worries are otherwise I do not see any worry let us look you are done last semester reports if not please revise your course because I will not teach devices course in analog okay the basic transistor shown here is an NPN transistor can be happy NP as well the symbol is

arrow coming out is NPN arrow going at the emitter is PNPN PNP typical NPN tungsten is shown here.

This is the emitter which is heavily doped and plus some times n plus then small base width shallow dot a low doped P region which is the base connected and a little lesser dope than n plus is the collector region and this is the symbol of currents we are shown IB enters I enter so as I see this is the symbol in real life these symbols are no meaning why because current can start or the base the circuit wise the current can be shown only starting from positive terminal of the battery and should end at the negative terminal.

That is what the circuit is word about so irrespective what happens inside or whatever you may say for the device actually currents will start from power supply and will go to the ground that is the way it will happen now you may have to say no but you are showing this symbol and you actual current is this yeah that means the electron current going down but the actual current is going up is that clear.

So symbol and devices and symbol in circuit me sometimes very because the carrier which you are going to use in different devices this is a symbolization but do not worry this is for device in real life please remember circuit always will start current from positive terminal of the battery and will end at the negative to form a circuit unless it returns no circuit unless it work it is prom no analysis no current okay.

So there is a universal thinking in bipolar as you must have learned that the emitter current is always some off base current and the collector essentially what we say when the emitter electrons emitter injects electrons part of the electrons are recombining in base okay constituting the base current and the rest will go to the collector okay.

However in this there are some leakage currents we are not added but that may happen because there are two diode they may cancel so basic idea in case of circuit they take a desire circuit we may again reality devices small changes may occur but in circuits emitter current is always some

off base current plus collector this is our Universal theory we also know the collector current as I just now said not all electrons starting from emitter which collector.

There is a transport essentially because of recombination because of the efficiency of this emitter Junction and the base transported us there is a term which is called alpha t is based on a factor and emitter cannot have 100% efficiency so it as if the emitter efficiency gamma and the product is called alpha and IC is equal to alpha times I please take it these are circuit equations some modifications will be done in real life in case we need leakage currents to be added but normally this will be followed in most circuit cases.

We also know that the collector current/emitter current is alpha but collector current from this equation now use IE=IB+IC in this equation and then you will get IC/IB=beta which essentially from this term will come alpha upon 1-alpha and beta is essentially called common emitter forward current gain is the major parameter in all our analog circuits beta.

How much is the why because typically the inputs will be given at the base and how much beta times it will provide you the collector current so larger the beta larger will be the gain and therefore it is called gain typically gains can be as low as 1, 2, 3, 4 or 5 and can go up to 500 to 600, it cannot become alpha=1 beta is infinite actually, but alpha can never become 1 because alpha T cannot recover.

There is there will be time there is a finite time or recombination time in the base and there is not all electrons there will be reverse current also coming from base to the emitter so our gamma can never become 1 since gamma can never become 1 alpha t can never become cannot be infinite guaranty alpha will never become 1 so as high alpha you can get 0.999 that may give you thousand meter is that correct.

So maximum possible alpha you can get in most technology of device may be of that order which means not more than 600, 500 meter can be cheap is that this is technology limits if you can do better someday yes you can improve but that is really difficult I am not saying impossible we also say if you want little more accuracy I see is not only alpha that is plus some collector

leakage current which is called when the emitter is open as how the collector is open whatever is the collector base emitter.

Junction is open whatever is the collector current you get is called IC okay, we like devices you please read if you are not if you do some of you do not know or not understood you come me separately out I will explain a devices much more detail if you wish so, so right now I assume that in this is what I can use no circuits but if I want little more thinking I may add a term ICO to that I see of course is decided by ICS which is reverse saturation current of collector Junction x1-alpha R x alpha.

What is alpha, alpha F is that is collector acting like emitter, emitter acting like a collector is called reverse operation so alpha is the reverse operated alpha of that so IC/IE oppositely if you do it it is called alpha that is emitter becoming collector and collector becoming I mean essentially what saying in normal operation base emitter Junction is forward biased base collector Junction is reverse biased if you do the contrary base emitter Junction reverse bias and base collector in forward bias the carriers will come from the other side okay.

That is called alpha R so it can be proved by device theory that ICU is reverse saturation can I see s into 1 minus alpha R and that you can evaluate IC by a measurement you can do easily just open that circuit and measure the current in the actual circuit that is nice you also have one Kirchhoff's law always followed VCE is if you see this BCE and this is your BBE and this is your BBC.

You can see from here at between the two nodes you can only one voltage between any two nodes you can have only one voltage between this collector Junction and emitter Junction if you are the voltage VCE, but if you go through the other side of the loop you go from emitter to base and base to collector and the sum total of base emitter voltage plus base collector voltage must be equal to VC.

Actually this is the fun that the operation of the device which becomes saturated that both junctions become forward bias and therefore VC goes down is very interesting maybe someday

we will explain that okay that is what did digital circuitry will bond okay that VC should go down to 0.1 volt because that is the zero state of the logic in analog will never like to do that because what do you do yesterday I showed you a figure.

I want to win linear region of V0 weighing characteristics all the time okay therefore, I will never like to go to saturation area I will remain in the linear area all the time if possible so this equation is again valid all the time VC is always equal to VBE+VBC okay, this is Christophe law between two nodes same voltage can occur okay, okay the second third issue, which is of relevance in bipolar.

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(Video Starts: 01:08:26)

There is something what we call large signal model but what we are interested latter is small signal model but let us see what a large signal we said this is what we are showing you right now DC values essentially is called large signal models typically a bipolar transistor can be shown as base emitter junction is the diode base emitter junction is a diode and base collector Junction actually has a collector current.

Which is beta times IB so it is a current source depending on the base current which is decided by the diode at the base emitter junction is that correct whatever VBI apply e to the power Q we why is the diode current flowing and KT if it is different device and different regions but the diode current is the base current is that clear is that clear diode current is the base current and Beta time that base current is collector current that is the word okay I must show you I see here.

IC is Beta time that is what equations we wrote that is the representation of what I wrote and show you in this circuit now why do I want to always show some numbers as representation because at the end of this when I solve a analog circuit it is a circuit there is no device there I cannot use diode there is that correct but then I have to write exponential term this I cannot solve in a circuit such thing.

So what should I want I want equivalent of that in a circuit so I say okay when the diode is on it is like a battery of VbE on which may be more than 0.6 volt cutoff is 0.6 may be 0.7 volt which

will assume so VbE on in all circuits when it is this will be a shown 0.7 volts okay if it is less than 0.7.

Say it is there going towards off state now if it is less more than 0.7 it will go to saturation say this 0.7 volt is not exact number actually whatever bias you are accordingly it will calculate but for circuit people 0.705 0r 0.699 is good enough is that clear so something which I am now representing is for circuit analysis device people may not say cut it earlier book a car user if not but I are asked about the for us that is good enough.

Similarly if you are looking for PNP since it is the opposite polarity device the diode is shown opposite by P lower and above here P above and lower is that clear so it is just NPNPNP it represents the base current if you are really looking for is the saturation current divided by beta into exponential VB/VT what is VTI wrote it is KT/Q it is called thermal voltage VT is called but this I will stop writing afterwards because in VT in the mass transistor is what the threshold voltage or turn on voltage.

So I should not conclude that we T with this VT just now I wrote VT but later on I may use KT/Q everywhere so that no misgivings about threshold voltage of mask on the scalp and VT are here as thermal voltage so similarly I can say we be on IB beta times IB this is for PNP is that okay simple models what is not missing here there are many important parameters right now I are not it for example there are resistances capacitances whatever is going to happen right now.

I am not sure this is called simplistic model of a BJT will add on terms in real life oh it NIDA can add something I will what is the wave method will first many times what did we do we actually looked at the device and found some numbers and added what is the inverse way we did measurement and this simple theory did not meet (FL: From 01:12:49 to 01:12:50)after I had gotten a honey hot rod is this turned under there for drop the guy.

(Video Ends: 01:12:50)

So there are two ways of learning any circuit one is do it and do not find the correct theories for act theory from your side which with the model or you create a good model and then verify on their oh it works it will so when we give a lab many students ask me is a rap now a theory

covered on your lab did yeah nothing happens because you do first and then when you start looking at theory oh.

Now I understand why, why it happen or you can even start thinking earlier so do not go and tell the lab professor has not taught this how can you give me X now you do an extra not a wise and then learn the theory bag or learn the theory first do external later so it depends on division choices but this is where I look at it so every time we used to give a lap.

(Video Starts: 01:13:41)

So this model which I shown you is called large signal model one minute and this is called small we will come back later next time this is most important thing which I want to use this is not for BJT for every model but here it is shown for this we will say the total base current let us say is represented by capital I small b is that correct total base current is small signal current which I represent at small ib okay plus the DC base current which is capital I capital B.

So small signal +DC=the total current is that correct so total current is represented by capital I small b=ib +IB is that clear this is my symbols so if I write one way or the other you must understand what which turns I am writing in the case of collector there is some issue because see in which hotel bar I is very difficult to draw okay.

So I made smaller one as a bar to show that so this is total IC current which is equal to DC calculator current +AC or small signal current IC okay this is a transfer output characteristic a transistor we'll come back to it to next time but most interesting part from the circuit why I showed you this too just now before we go ahead I plotted collector current versus VCB that is output what is VCB in that figure if you see my VCB, which is the in the common emitter circuit this is your output voltage VCB is that current this is your input current okay.

This is your output current let us look at it this is your IC this is your VCB if this I ground this is my output we see that sort of thing okay Oh I made a mistake I should have I am sorry BC I am sorry I apologize okay so if I plot out I kept saying it but I think in writing I am a mistake so if I plot VC versus IC current which is the output characteristics of a common emitter transistor then for different days current.

I see different characteristics as I increase base current the collector current beta times IB and in non cases it may not be linearly related it shows different regions of bipolar operations however the issue which I am going to show in real life if all these characteristics are different IV are extrapolated back okay they all meet at a single voltage which is called hourly voltage what is the only voltage in device if I start increasing VCE essentially I am increasing VCB.

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Please tell your VC=VCB+VVI may fix but as I increase VCB I increase VC is that correct. So if I increase VCE as I increase what will happen to base collector Junction its depletion layer will start enhancing depends on the doping on both base and collector wave majority it may deplete first towards collector because it was kept and okay so most of the voltage will be sustained in the collector region.

But amid this will also start getting depleted is that correct and some voltage base may get punched emitter and collector may get shorted through a depletion layer that is called punch through or called oddly voltage. Does that correct at that voltage at that VCB or VCE we call the device is punched okay this is very important parameter for us because if you see this slope.

Please look at it this loop for any current this voltage this is very high typically early volt will be 50 volt and 100 volts VC will be 5 volt or less power supplies at best 5 volts typically volt divided by the current is what voltage divided by current is what this slope resistance which is this characteristic. I am drawing output, what resistance I am talking output resistance so if I am given early voltage I know the output resistance of their transistor immediately is that correct this.

I know this at any given current this divided by this is my resistance and they should all show roughly same slopes I mean same because they meet at same point though R0 varies with every base current to some extent because your slopes are different okay, but majority at that current wherever you are operating you will know what is the output resistance of this circuit so from the circuit point of view.

If I am given an early voltage directly, I am telling you whenever you will bias it at a given collector current, I know what is the output resistance and children is that clear that is why I showed you the slide that many a times R0 is not specified, but early voltage is specified okay and from there are 0 is known to us is that clear that is how we actually start watching matter, thank you for the day.