**Design Principles of RF and Microwave Filters and Amplifiers**
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**Module No # 4**
**Lecture No # 20**
**Measurement of Nonlinearity**

Welcome to this twentieth and last lecture of this course on RF filter and amplifier design we have seen various amplifiers design and in last two lectures we were discussing about power amplifiers particularly non linearity. So power amplifier design nothing new from the other amplifier designs for a gain etc but we need to find out what is the dynamic range where we need operate the device. So we have seen the concept of 1DP gain compression point.

We have seen the concept of the danger of third order inter modulation product, we have seen the third order intercept point and based on that we have characterized the spurious free dynamic range. Now we need to find out how to measure the spurious free dynamic range or third order intercept point.

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## CAN $P_{OIP}$ & $P_{1\ DB}$ BE MEASURED ?

Two tones of strength -20 dBm are applied at 2 GHz and 2.01 GHz to an amplifier with 10 dB gain. Connect the output to a Spectrum Analyser. The following observations are made.

| Freq. (GHz) | Spectral Power Amplitude (dBm) |
|---|---|
| 1.99 | -70 |
| 2.00 | -20 |
| 2.01 | -20 |
| 2.02 | -70 |

That will do now so the question is can the third order intercept point output intercept point POIP3 and 1 db gain compression point can they be measure please remember in this title this db that actual thing should be like this db but with power point that this problem comes.

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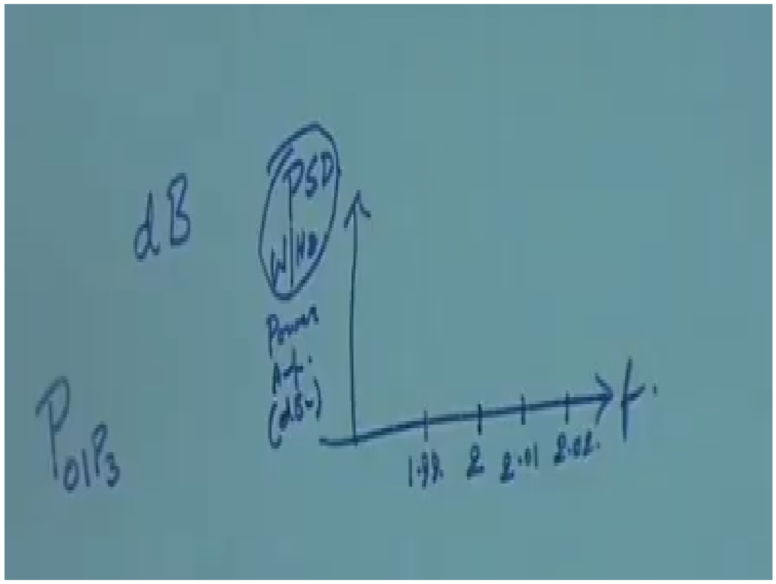


Now the problem is like this that the 2 tones let us say of strength – 20 dbm each are applied and their frequencies let us say at 2 gigahertz and 2.01 gigahertz I say that the previous lecture that in 2 tones test the two frequencies are distinct 2 gigahertz and 2.01 gigahertz are distinct. But they are in far off because they should in a band. So let us 2 and 2.01 which means and that it is already separated by 10 megahertz and they applied to a amplifier 10 DB gain.

Now connect the output to a spectrum analyzer and following observations are made. You see that this is the way of measuring this third order intercept point poip3o there is also another mistake that poip3 should be there that in the title because this is the third order intercept points symbol and now let us see that connect you need to you apply this two different tone let us say of this two with -20 dbm power and amplifier is of 10 db gain.

Now connect the output to a spectrum analyzer and let us say make this observation that had 1.99 you know spectrum analyzer means already we have covered spectrum analyzer in detail in one of the NPTEL lecture, so we have frequency here so we have the power spectral density. Here you can it in power spectral density watts per hedge.

So now there you measure what is that 1.99, you will there are 1.99 there is one (()) (04:44) because 2 – 2.01, 2- .01 that will be this 1.99 there is another at 2 there is another at 2.01 there is another at 2.02 and the spectral power amplitude here you can also have in the Y axis the amplitude that is in dbm so you have measure that.

In spectral analyzer you can change, so if you put it in power amplitude let us say that the values are these. From this you will have to determine what is poip how will do that.

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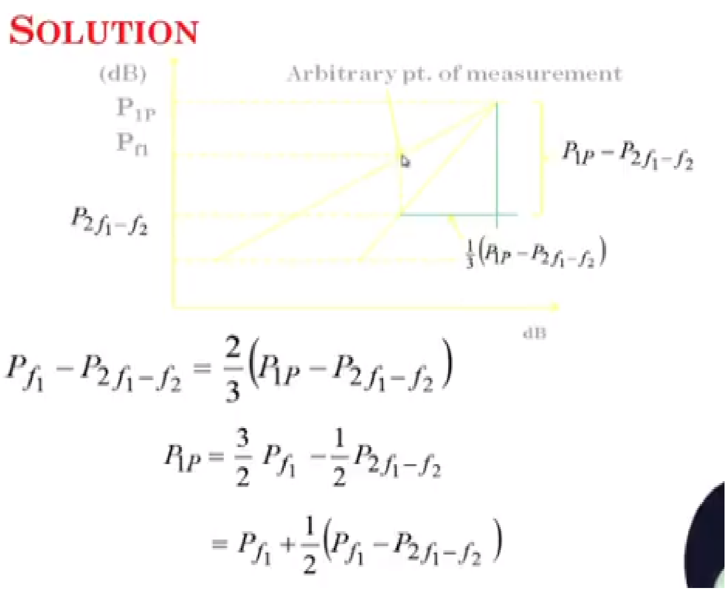


So let us say this is the arbitrary point of measurement and here we can have shown that this power of the F1 component minus power of the third order inter modulation thing. So at this point you see this is my PF1 and this is also this is my p2fl – 2f2 so this point is this. No I know this difference in this two and from this slope I can then relate because I know that this slope is this is of Slope 3, this is of slope 1.

So I can find out this point basically I need to find out this point. So that point it is pip – p2f1 – f3 and this point is one third like this so this simple mathematics will show you that Pip is nothing but pf1 + half of pf1 minus these and then we can find out that what is in our case.

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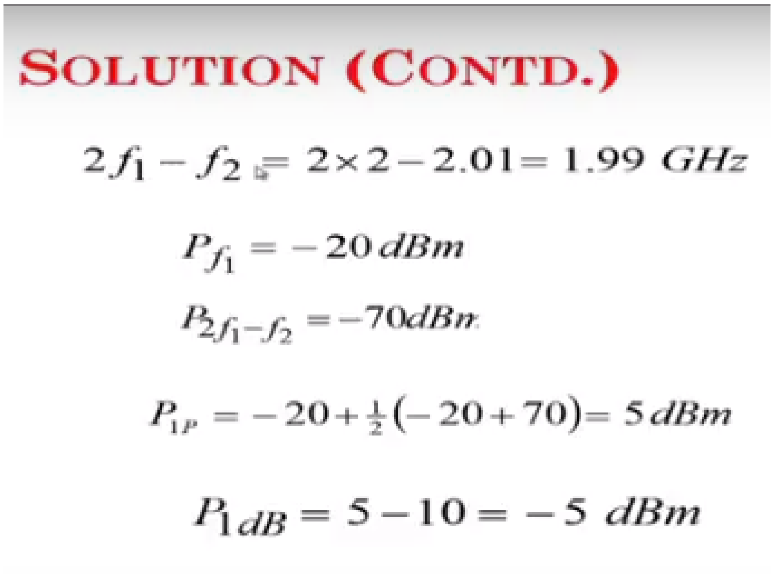


2f1 – f2 is 2 into this is 1.99 gigahertz pf1 power at frequency one is - 20 dbm power at 2 f1 – f2 that means at 1.99 we have rate the value – 17. So pip we can find out as these 5 dbm so p1db we know that 9.6 which I have set to be here roughly 10 but actually it will be 5 – 9.6 so that will be roughly 2 -5 dbm. So now I know this also you see that if I a cascaded system two amplifiers or one amplifier, one mixed etc.

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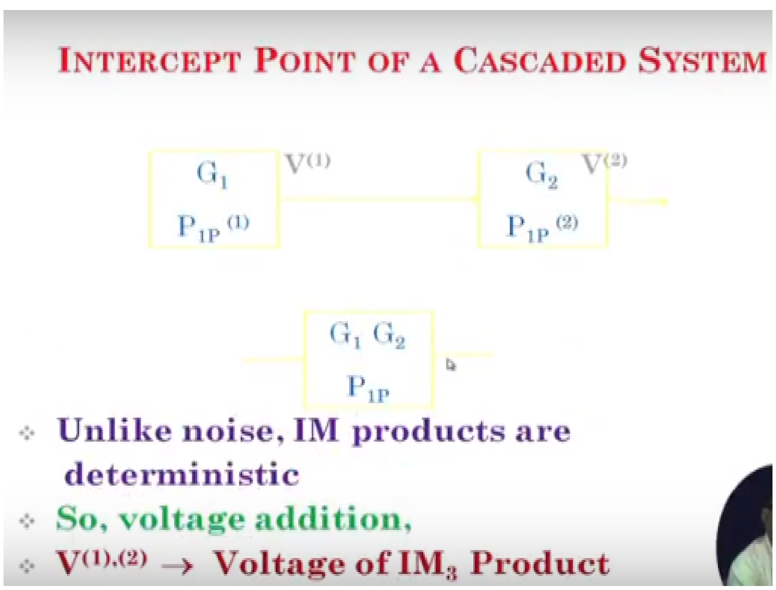


And they are cascaded let first system as gain G1 the intercept point poip1 this as gain 2 g2 intercept point 2. So we know that they are overall gain will be g1, g2 let us say they are overall third order intercept point is pip. Now unlike noise IM products are deterministic. Please remember that so voltage will add so voltage of IM3 product that will be simply added.

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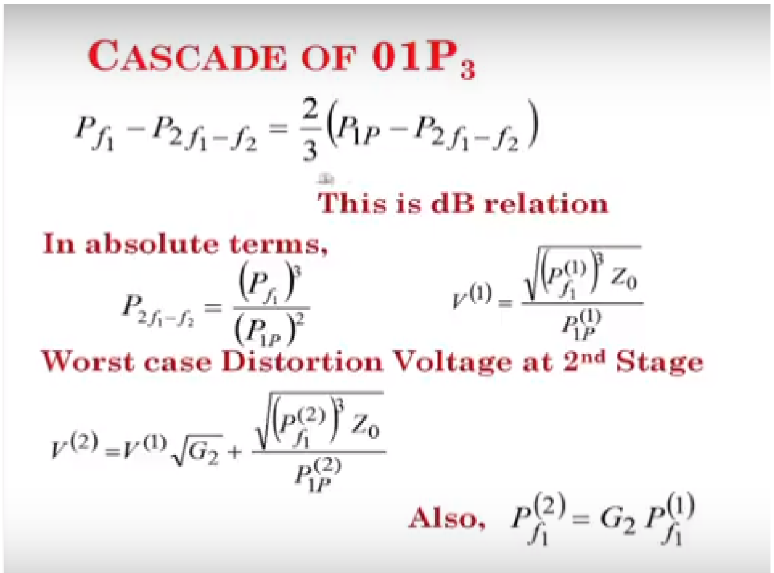


It is the deterministic symbol now cascade of OIP3 so we know this is the DB relation in absolute relation this is these so what is the voltage corresponding, I can relate that with a characteristic impedance Z0 form this I can find out the voltage worst case discussion worse case distortion voltage at second stage is this, so also this is the another the power for second order second stage. So now cascade you continue so write down overall system I have these.

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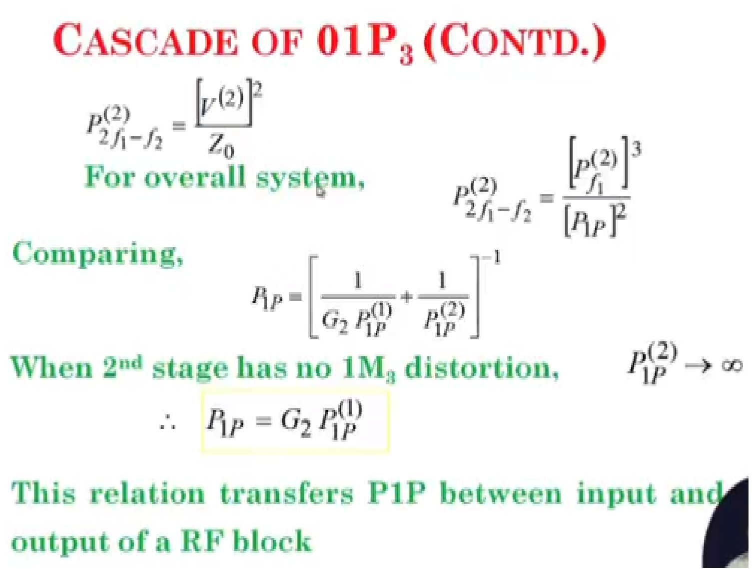

And if from individual one we have previous written this voltages so now I can relate compare and that will show you over all intercept point will be these plus this. So when second stage as no IM3 distortion that means Pip2 If it becomes infinity that means at very high value the intermodulation product will catch up.

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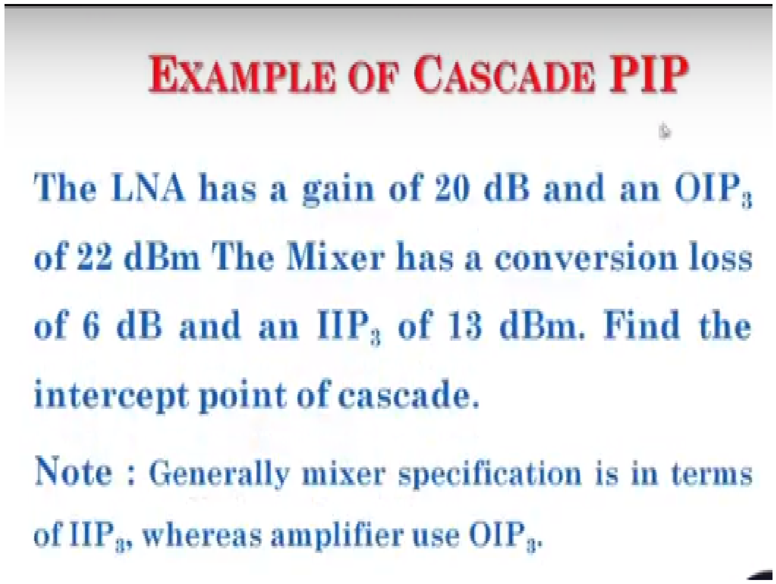


So that means there is no IM3 distortion so if we put that then PIP becomes G2 PIP1 so this relation transfers PIP between input and output of a RF block. You see that the from 1 to the overall so that transfer the PIP between input and output. Example of a cascade PIP The LNA ha a gain of 20 dB and let us say and an OIP3 this output intercept point of 22 dbm.

The mixture which is the next blog generally after the LNA has a conversion laws of 6 dbm you know, mixture have always a conversion law because it is a nonlinear system. So in conversion because it is changing the frequency, frequency is converting in that it always suffers as loss. Let us say that loss is 6 dB and an IIP3 of 13 dbm find the intercept point of cascade. Generally mixer specification this is another industry does it like this that mixer specification is in terms of IIP3.

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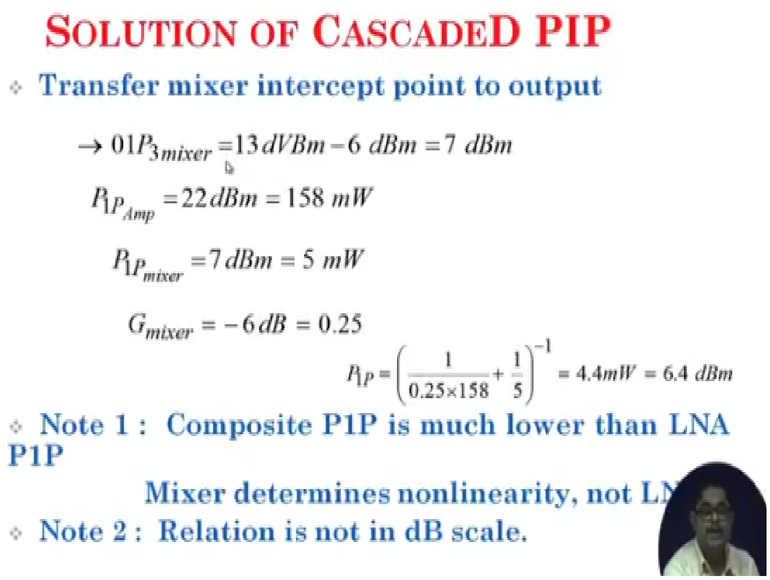


Amplifiers are generally used output intercept point mixer sorry input intercept point now transfer mixer intercept point to output we have just seen the relation that can give you that OIP3 mixture we can find like this. Now amplifier is also output side mixture is also output we have converted that so now find out that gain is this so overall PIP3 from that formula that is this 6.4 dbm.

So composite PIP you see is much lower than LNA PIP why because mixer actually determines the nonlinearity actually even though we have then large signals this case but mixer it determines always the nonlinearity so composite PIP is much lower this is important because in the overall system you need to find out the nonlinearity so even though single mixer is the quite good amount of nonlinearity.

But due to the presence of LNA you have this relation also remember that this relation is not in dB scale that previous also I said I think yes you see that this relation is an absolute scale you see all this in derivation we have used it to absolute scale this is not in the dB scale you can convert into dB scale if you want but as it is this relation in dB scale.

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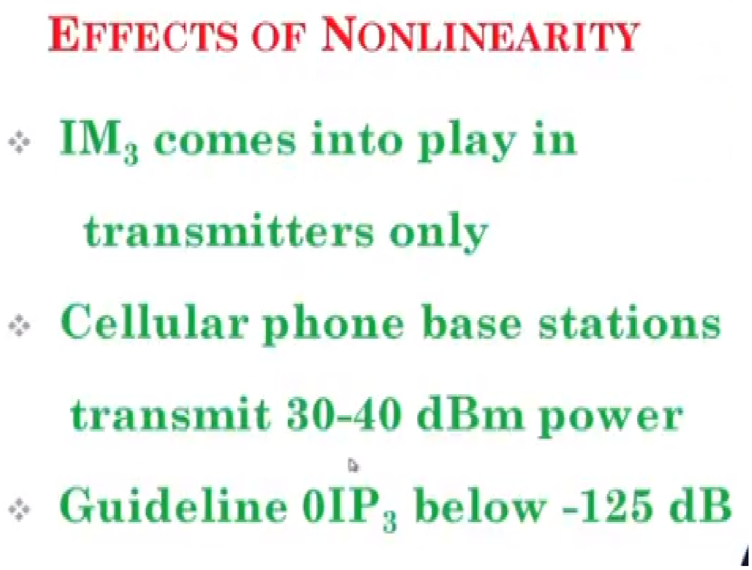


Now effects of nonlinearity, you see that this intermodulation product third order intermodulation product comes into playing transmitters only though this example we have shown for LNA mixer. But there this nonlinearity does not come but mixer is a (()) (12:36) nonlinearity device that's why we have talked about. But generally in transmitter in then power amplifier plays the final stage this comes now a cellular phone base station they transmits typically 30 to 40 dbm power.

So they are there is chance of nonlinearity because they in this levels you cannot it is a small signal lever so they are for gsm standard the guideline OIP3 you should have your output intercept point below -125 db. Similarly also satellites suppose satellite base station when it satellite ground station when it sends to the satellite the power amplifier it is a huge amplifier megawatts of power its sends. So that time also you should specify in that power amplifier what is the OIP3 what is the spurious speed dynamic range etc.

So similarly form the satellite when satellite in its (()) (13:52) it send there also there is this OIP3 or IIPs its specifies generally the power amplifier this specify OIP3. So you need to specify OIP3 for any power amplifier and this is the way it should be calculated.

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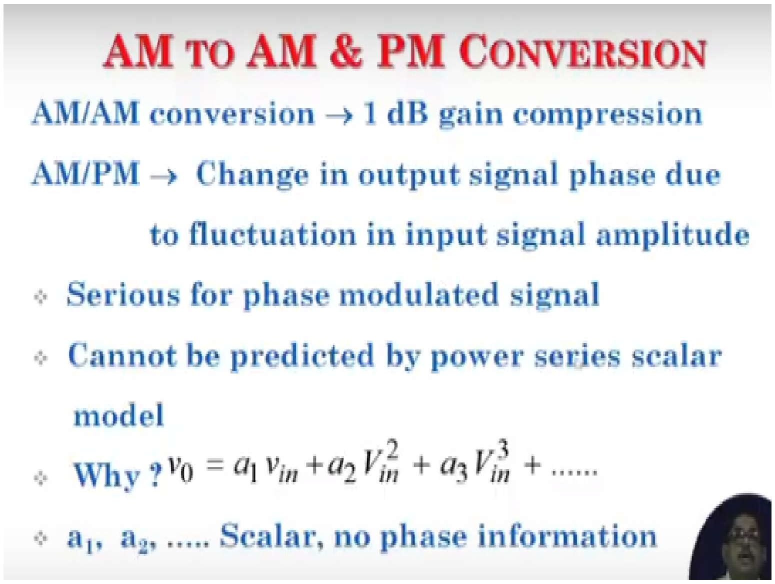


Also you remember that due to this nonlinearity there is a always whenever the nonlinearity you are having an amplitude modulated signal, amplitude modulated signal is converted to a another amplitude modulated signal. That is why we get 1 DB gain compression so you see what was the input side amplitude modulation when due to non-linearity we have seen all your the gain things can get changed if you consider that third order intercept point your gain gets changed and that is why that characterization this M to M conversion is 1 DB gain compression.

Whereas there will be when you are changing the system when you are squaring basically we were changing playing with the frequency so there will be change of phase also. So you get a AM to PM conversion change in output signal phase due to fluctuation on input signal amplitude it is for phase modulated signals it is series cannot that this thing cannot be predicted by power series scalar model. In our what we have seen we can predict this AM to AM conversion.

Because we have a system model but you see our system model is this. These was the model which we used that V0 = a1 vin + a2V2in square + a3 V3in square now here you see Vin Vin square Vin Cube all this basically we are assuming Vin the amplitude part Vin and this a1,a2,a3 they are we are assuming scalar quantity but when you make them better this Vin then Vin we should consider as a phaser with both amplitude and phase if we do that then this expression won't be simple their square.

We will have to use that conjugate relation and we will have to consider so we should have a1,a2,a3 all of them should be vector quantities or phaser quantities and this Vin also when we are squaring  we should remember that we are squaring a complex number appropriate that mathematics we should bring. If we do that then we can find PM that is a more complicated model at your level well you do not required in the M.Tech level we do not expose you to that when do the research consider this as complex measures and then you can find out this.

So but you remember that there is a phase modulation when we have nonlinearity because you are changing the when you input signal is fluctuating you see Vin is changing you are squaring, cubing it. So that is changing the phase of the output signal. So with that I think we have covered the whole series of this RF filter and amplifier part their analysis, their design hope this knowledge will help you.

Hope you have understood this concept and then you will start designing your amplifier and filters RF amplifier and filters microwave amplifiers and filters. Obviously the more and more you design, more and more you practical designs, you get better insights and also always try to emphasis that design means it is an open thing it is also part of art. Where do you put the source impedance where will put the load impedance that more from your practical design experiences you gain.

The this theoretical background helps you to understand the ok this is you playing ground how you play that is how you practice. So practice more and more all this RF and RF filter, microwave filter, RF amplifier microwave amplifier design I think you will enjoy throughout your life. Thank you.