Experimental Physics - III
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Lecture - 10
Lock in Amplifier

So, today is will discuss about another important tools and instrument in solid state physics laboratory. So, that is Lock in Amplifier. So, lock in amplifier, what is lock in amplifier? For this the use of this lock in amplifier how to use so, that I will discuss.

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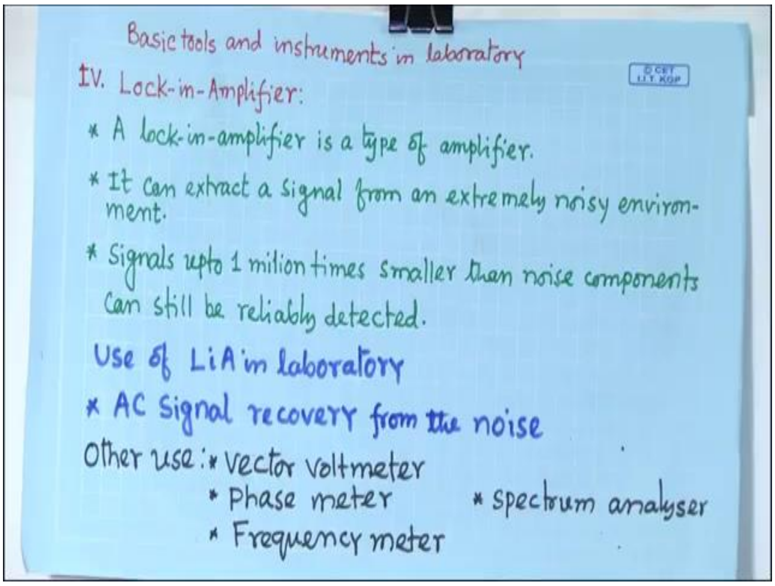

So, lock in amplifier is a type of amplifier, you know that is always we amplify the signal and in different most of the cases you have to amplify the signal to process it. So, amplifier is a common in electronic circuit. So, lock in amplifier is a type of amplifier, it can extract a signal from an extremely noisy environment, signal up to 1 million times smaller than noise components can still be reliably detected.

So, what is lock in amplifier? Lock in amplifier is an amplifier, which can single out the signal from an extremely noisy environment ok. So, use of lock in amplifier is as I told is mainly primary use of this lock is amplifier is AC signal recovery from the noise. Other use it is used as a vector voltmeter, phase meter, frequency meter, spectrum analyzer, but this part I will not discuss.

So, this primary use of this lock in amplifier as a single out the signal from a noisy environment. So, that application I will discuss.

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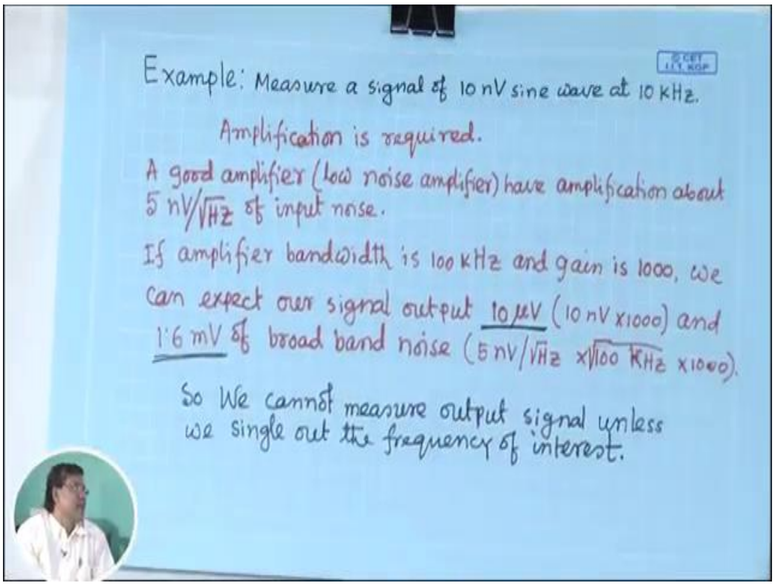

So, let us say we have to measure a signal of 10 Nano volt sin wave at 10 kilo Hertz ok. So, you have a signal of 10 nano volt sin wave at 10 kilo Hertz. So, how we will deduct this signal? So, always this is a very weak signal and we have to amplify, it we will use amplifier. So, when we use amplifier say a good amplifier has amplification about 5 nano volt per root square Hertz of input noise means, this noise having random frequency that also will be amplified.

So, this rate of amplification depends it is the it depends on the frequency of this noise ok. So, noise can have this all sorts of frequency. So, that amplification depends on the frequency. So, that is why this good amplification have this 5 nano volt per square root of Hertz. So, that is the amplification in case of noise.

So, noise if it has this amplifier if it has the bandwidth, about say 100 kilo Hertz means, all amplifier has bandwidth means within this range it can within this frequency range it can amplify ok. So, that is called bandwidth. So, if this amplifier has the bandwidth around 100 kilo Hertz.

And, gain is say 1000 then we can expect that our signal of this signal 10 nano volt, it will be 10 microvolt. And, noise will be; noise will be 1.6 millivolt of broadband noise ok. So, because noise will have all sorts of frequency so, it our amplifier have this 100 kilo Hertz band bandwidth. So, within that bandwidth this all noise will be amplified. So, ultimately so, this into the that bandwidth into this gain. So, from there you will get 1.6 millivolt noise ok.

So, when our signal is 10 microvolt, our noise is 1.6 millivolt, so, if it is in microvolt and then it is in millivolt range ok. So, you think the just normal amplifier we cannot we cannot get our signal, we cannot neglect the noise, because it is higher this noise it is you see 1000 times or 100 times higher than the signal. So, we cannot measure the signal using the normal amplifier ok.

we cannot measure out signal unless, we single out the frequency of interest ok. So, we need mechanism frequency dependent measurement ok, frequency depend dependent measurement to or. So, that we can take out the signal of our signal of our interest signal of the specified frequency. So, that type of measurement we need and that can be done that is the purpose of this another amplifier that is called lock in amplifier. So, how to single out the frequency of interest from the noise so, that that is done by the lock in amplifier.

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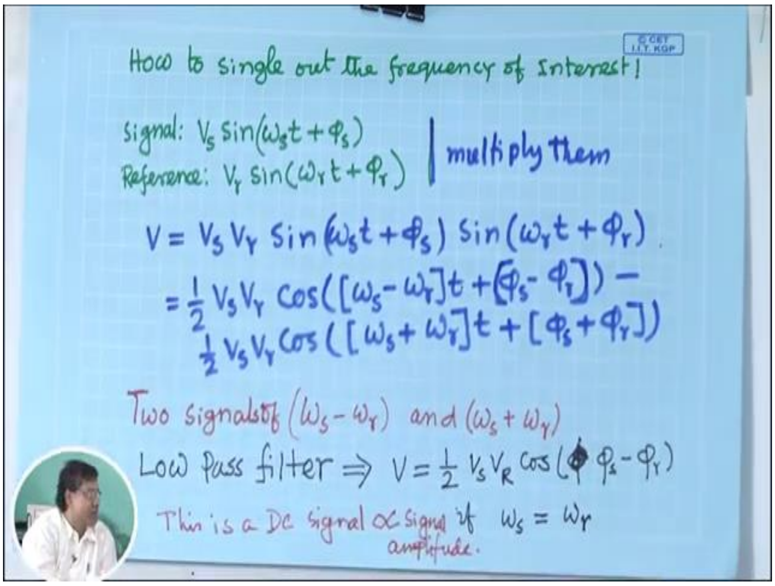

So, for that, the principle of the lock in amplifier we can understand from this calculation. So, we have signal that is a V s sin omega s t plus phi s ok. So, you know this is the amplitude and this is the frequency and this phase, this is the initial phase of signal. And, say it is we are telling it is reference signal or this is the signal of our interest and this another this is reference signal say it is V r sin omega or t plus phi r ok.

Now, if you if we multiply these two, then we will get say V equal to after multiplication you are getting this. So, sin a sin b 2 sin a sin b equal to cos a minus b minus cos a plus b So, 2 half I have taken. So, 2 then this you can get cos omega s minus omega r t plus phi s minus phi r minus, another time half V s V r cos omega is plus omega r t plus theta s plus theta r theta r ok.

So, here we are getting 2 signals of omega of difference of the frequency and another one is addition of the frequency ok. So, 2 signal 2 signal we will get. So, now if this signal after multiplication this signal is passed through a low pass filter, low pass filter, when a low this low frequency signal will allow to pass will be allowed to pass.

So, that is called low pass filter and high frequency one will be half circled ok. So, then this higher frequency part this addition of these 2 frequency. So, this part this part will be stopped only this difference the low frequency difference of this 2 frequency. So, that signal will pass through ok.

So, using low pass filter we will get from here. So, V equal to half V s V r cos phi s minus phi r, if omega s equal to omega r; that means, if frequency of signal and reference signal are same then in that case we will get V equal to this. So, here you can see there is no time dependent part is a constant it is a DC part DC value ok.

So, cos theta phi s minus phi r of this is independent of time. So, it is the difference of the phase initial phase of the signal and the reference. So, this is the this is a DC signal, which is proportional to the signal amplitude, which is proportional to the signal amplitude and here is V s this V r etcetera this you can so, they are constant ok. So, whatever the DC signal in this process whatever the DC we will get that is proportional to the signal amplitude ok.

So, that means, we can get output which is proportional to the signal. So, this way if we for the mathematics I showed you, if this way if we can build up an instrument. So, that instrument will be able to give us the output, the output as our signal, but it is not absolute value it is a proportionate value, but it does not matter. So, we will get the output, which is proportional to our signal and that we are taking out from the noisy environment.

So, from here why I am telling so, here you have signal and you have with the signal you have noise of different frequencies. So, if you so, this signal this plus some other term other many terms are there having different frequencies ok. So, if we multiply with this reference one, multiply with the reference one then you will get many terms. And, all terms will be eliminated all terms will be all terms will be eliminated right, except the term except one DC part ok, except one DC part ok.

That DC part is this will be the DC part, this DC part we are getting because in which case we from which time we are getting where the frequency is same. See, if the noise is there which frequency is exactly same to the single then we cannot, we cannot remove that one, but it is unusual it is unusual ok. And, this frequency here this low pass filter will use as well as this instrument should have very, it is a is phase sensitive detection phase sensitive detection ok.

So, it is this system should have very narrow bandwidth generally this phase sensitive detection means, bandwidth is generally in milli Hertz it is the it is in milli Hertz in our example normal amplifier it has few 100, few 100 kilo Hertz bandwidth, but for phase sensitive deduction this bandwidth can be it is in milli Hertz ok.

So, this so, following this mathematics you can see if any other term noise terms are there frequency are not same with the reference frequency, because reference frequency we are choosing in such a way, that frequency should be equal to the signal frequency. And, so; obviously, this other noise frequency random frequency, it will not be same as that one then this part will be time dependent and the higher term when you filter out, for higher frequency term will be filter out ok.

And, lower term there one part will be DC. So, that way we can single out these signal from the noise ok. So, in lock in amplifier how this condition is satisfied? So, that I will show you, so, another it is called x y mode. So, here you can see it is an in here, you can see that now this is my signal this is my signal as an output from the lock in amplifier ok.

So, now in lock in amplifier, if you have some position that this we can make this phase difference 0 ok, make this phase difference phi s equal to phi r then this part will be 1.

So, this DC part this magnitude will be maximum right, because this cos phi this term will give you some fraction, it is a less than 1 between 0 to 1. So, this term will be reduced by this factor. So, if you can; you can if you can make it one then what will happen you can maximize your signal ok.

So, the in lock in amplifier, there is an option that we can change the phase of the reference signal and then you can try to make this 2 equal seeing that if you can see this amplitude ok. This amplitude will be maximum when this phi s will be equal to phi r. So, we can change the frequency of the reference signal to maximize this one; that means, that time this part will be 0.

And, now you can check it whether you have this 2 are phi s and phi r is equal or not just after getting the maximum value of this one, just you can add 90 degree you can just add 90 degree phase additional phase with this phi r ok; that means, what will happen? So, now, so, cos 0 was there be, because phi s equal to phi r, now it will be cos 90 degree, cos 90 degree means it is 0. So, this value will be 0 ok, this value will be 0.

So, now you see this value is looks to us that it is it depends on the phase; it depends on the phase ok. So, it is also possible to make it phase independent phase independent ok. So, how to do that? So, see that if we in lock in amplifier. So, what we are doing, we are this signal term is multiplied with this reference and getting this.

So, similar arrangement another channel will be there in that there. So, this same signal will be multiplied with the reference signal, which is which has additional 90 degree phase, which will have additional 90 degree phase what does it mean then this one will be cos omega rt plus phi r.

So, in one channel it will be, it will be, it will be multiplied by sin omega t plus phi r and in another channel these 2 will be multiplied with cos omega or t plus phi r ok. So, with so, whatever the reference here that is multiplied with this. So, another reference from here. So, it is a 90 degree phase difference between these 2 1. So, it will be then cos term. So, that cos will be multiplied with this one. So, this cos and sin sine cos. So, it will give you this after this calculation this term you will get sin term ok.

So, one term will be this with cos term, another term from second if multiplied with this cos term. So, you will get sin the same thing, but here sin ok. Now, you can think. So, I am getting two; one is this, another is with sin term. Now, this so, now you can think that, this if you have a vectors ok. Now, vector it has it will have 2 components; one is this sin term, if this is the angle theta ok.

So, this will be cos term and this another will be sin term ok. So, this for same amplitude so, amplitude is my half V S V R say it is proportional to V S. So, let me take with the signal amplitude ok, it is a proportional amplitude so, now, V s. So, my signal that is V s ok. So, V s now it will have two components; one is V s sin theta or sin phi and V s cos phi. So, that is why here this one in lock in amplifier this we are mentioning as a x term, and this sin term, we are mentioning as a y term ok.

Now, you will get your amplitude V S amplitude. So, your 2 term now V S V S cos phi V S cos phi and V S another term V S sin phi ok. So, V s cos phi is the x and V s sin phi you can take as a y. So, square root of x square plus y square is V s sin square theta phi plus cos square phi this is the one.

So, then we can tell this r equal to; r equal to square root of x square plus y square this r means this vector amplitude so, magnitude ok. So, then for our result our signal that is r in this case we in this way if you think. So, it so, x and y so, square root of x square plus y square that is r and that phi tan phi equal to y by x ok, because here y is sin that sin phi and x is cos phi. So, y by s that tan phi. So, phi equal to tan inverse y by x ok.

So, here you see it is phase independent, in this way r you are measuring r you are measuring it is phase independent So, r it is square root of x square plus y square ok. So, that way alone can measure to make it phasing phase independent. So, in that case you do not need to adjust this as I told is I can them make them equal and then this magnitude will be maximum that is what we to do.

So, whatever this is there fine we do not bother. So, another sin term we are producing from through another channel ok, doing the same way and this two, one is you are using as x another we are using a y; one is cos term and other is sin term. So, from there you can find out the amplitude or magnitude r and you can find out the (Refer Time: 26:41).

So, in there you can I will show you in amplifier lock in amplifier this r theta, you can measure r you can measure theta you can measure x, you can measure y. Now, interestingly if you note if this phi is difference of this phi s and phi r. Now, if here you see.

If I can if this phi is 0, if phi is 0, then what happens phi is 0 cos phi that is one means this is x terms. So, you will get x term is your signal V s and y term will be 0, just if you do add the phase 90 degree. So, then your x term will be 0 and y term will have the value ok. So, y term that value means that will be your signal ok.

So, whatever I discussed I will show you the instrument and I will demonstrate this instrument is a one basic instrument of the lab in higher class, and you will use in some experiment. So, I will demonstrate do the experiment later on, but today, I would like to show you the lock in.