Principles of Mechanical Measurement

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Module - 04
Data Processing
Lecture - 13
Electronic amplifiers & filters

Morning everyone, welcome back to the second lecture of week number 4, where we are looking to wrap up this particular topic on data processing. Now well in the previous three weeks we have discussed about different basic components of a measurement system, basic characteristics in the form of mathematical equations and also the analog to digital conversion or vice versa. This week we are focusing more on the output data means, once we have got some kind of measurement from a measurement system, generally in the form of a transducer whatever output we are getting how to record that and how to if required condition that to substitutable form, that is what we are talking about in this week.

Now whatever common measurement system that you will get, whatever may be the type of the input in at least 80 percent of the cases you will find the output is of electrical in nature. That means, your input may be displacement or temperature or pressure or something else, but most commonly you will find we are using some kind of transducer, which converts this movement or this temperature change or whatever may be the input to some kind of electrical output and therefore here we are focusing mostly on processing and dealing with electrical data and measuring electrical quantities like voltage and current.

So, in the previous lecture we have discussed about the option of measuring common electrical parameters like voltage and current both in DC and AC mode, particularly the principle of the arsenal movement which we use for measurement of voltage or current primarily a current meter, but can also be used to measure voltage, and we have also discussed about different kind of impedance bridges or bridge circuits.

Now, you will be seeing in the next week itself that in several cases our output actually is related to some or I should say the input is actually transduced to form of some change in certain impedance; like whatever may be the input like in next week itself we shall be talking about the measurement of displacement and there you will be introduced to the concept of strain gauges or potentiometers, where the input in the form of displacement is converted to cause in a change, cause a change in the value of some resistance. And then this resistance we then if we can measure the change in this resistance, then that can be directly related to the input whatever we are looking to measure.

Now, to measure the change in resistance we subsequently convert this one to another electrical output generally in the form of a change in output voltage using the bridge circuits. And therefore, measurement of impedance which can be resistance or inductance or capacitance is a very common mode of measurement in different parameters. So, that we have discussed in the previous class itself; measurement of pure resistance with circuits or DC circuits in the form of (Refer Time: 03:24) bridge and also several AC circuits which allows us to measure resistance inductance or capacitance something like the wine bridge or Maxwell's bridge etcetera.

Today we shall be discussing a bit further into that into the kind of circuits and then we shall be talking about different components of signal conditioning and finally, briefly touching upon the digital signal processing.

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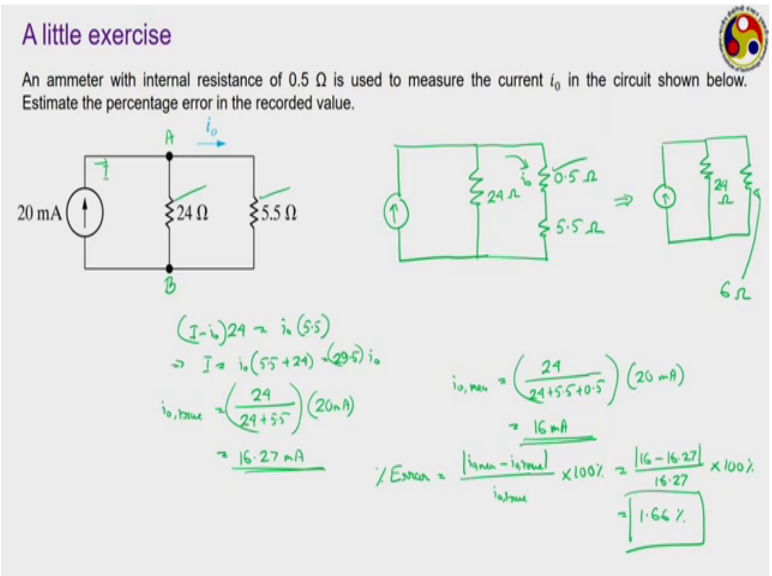

But before all of that let us quickly solve one problem using whatever we have learned in the last class.

So, here our problem involves one ammeter, first look at the circuit, we have our 20 milliampere current source and it is connected to 2 resistances which are placed in parallel one 24 ohm another 5.5 ohm. So, the ammeter of internal resistance 0.5 ohm we have to use to measure this current i naught; that means, what something the ammeter is not shown in the circuit, what it means that we are we are going to have the ammeter somewhere here. And if we consider the internal resistance of the ammeter, then the circuit can be modified to form like this, this is the 24 ohm resistance and in this circuit we are going to have 2 resistances.

So, this is the 24 ohm one here we have the 5.5 ohm one and here this is corresponding to the ammeter which can be viewed to be resistance of 0.5 ohm and we are having the current i naught which is flowing through this particular circuit, which we have to measure. Or I should say we are looking to measure the value of i naught, but what because of the presence of the internal resistance of this ammeter the what recording of i naught that we are going to get that may not be a perfect one there may be some error present and so, we have to calculate that error.

Now, this particular circuit can be converted to an equivalent resistance form. So, we have this as 24 ohm and this one can be the equivalent resistance of 5.5 plus 6 which is 5.5 plus 0.5 which is 6 ohm and 20 milliampere source.

So, how can we calculate this? The let us say this particular point is A and this particular point is B. When the ammeter is not present that is we are the measurement is not affected by the presence of the internal resistance. Then we just have 2 resistances this 24 ohm this 5.5 ohm and the ammeter is not there in the circuit.

So, if I is the total current that is flowing through the circuit, then the portion that is flowing through the resistance of 24 ohm will be I minus i naught and as the voltage drop across this point a to b has to be same with both resistors. So, we can write that is I minus i naught into 24 should be equal to i naught into 5.5 and this implies I is equal to i naught into 5.5 plus 24 that is 29.5 into i naught.

Now, how much is i how can we calculate the value of this i naught? That we are looking to find that is now related to i now how can we calculate the i? I we can be calculated using the equality of this resistances our current sources of 20 milliampere. So, the value of this capital I can be taken to be 20 milliampere and therefore, this I is equal to 20 milliampere accordingly we can calculate this i naught true value of this to be equal to as they are in parallel. So, 24 divided by this 24 plus 5.5 into this 20 milliampere thereby giving a true value of 16.27 milliampere, I pre calculated this number for you.

However when we are taking this 0.5 ohm in combination, then we can directly calculate this i naught measured will be equal to again 24 ohm is in parallel, but actual circuit we have 24 plus 5.5 plus 0.5 which is because of the presence of the internal resistance of the ammeter, into 20 milliampere you know I have pre calculated this comes to be exactly equal to 60 milliampere.

Hence percentage of error comes to be mod of i naught measured minus i naught true divided by i naught true into 100 percent which gives 16 minus 16.27; 16.27 should have been the reading, but actually we are getting 16, 16.27 into 100 percent which will be roughly coming to be equal to 1.66 percent. So, this is the error that is present in the measurement because we have not considered the internal resistance.

But if we; and your ammeter will be giving this particular values output; however, true current is actually 16.27 milliampere. So, 1.67 percent error 1.66 percent error is getting introduced in the calculation. This way if we take the internal resistance into consideration, we can easily evaluate the error that is present in the reading of any voltmeter or ammeter.

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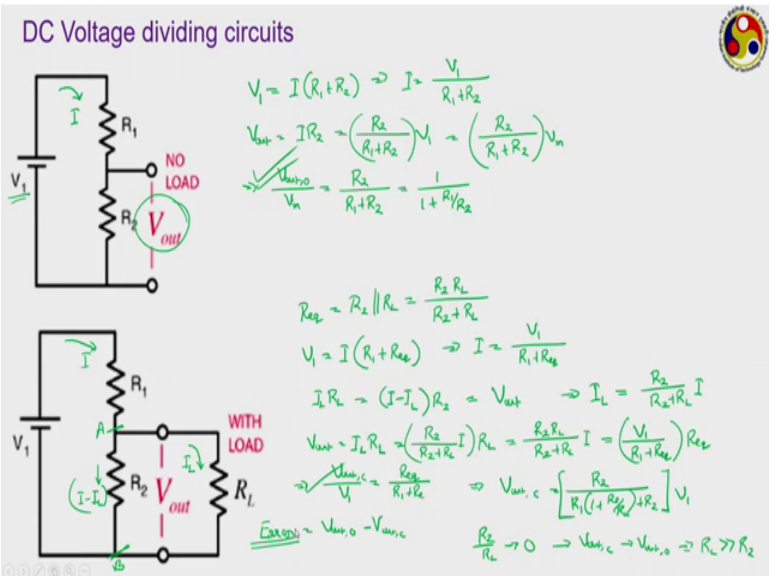

Now, let us move to another circuit which is known as the DC voltage dividing circuit. The voltage dividing circuit is nothing, but converting the output or scaling the output to a form as per our requirement. Just look at the circuit that is shown here. Here we have a voltage source V 1 and there are 2 resistances connected in series R 1 and R 2, then V out if the voltage output across R 2 is given as V out then we have to calculate the relation between this V out and V 1.

Let us say I is the current that is flowing through this circuit, then we can easily write as R 1 and R 2 are in series, V 1 will be equal to I into R 1 plus R 2 or I is equal to V 1 by R 1 plus R 2, then your V out will be equal to I into R 2 giving you R 2 by R 1 plus R 2 into V 1 or we can also write this to be as R 2 by R 1 plus R 2 into V 1 or if we write in ratio form V out upon V in my V in refers to V 1 of the input voltage is R 2 by R 1 plus R 2.

What effectively is showing that in the output voltage V out, means once we are given with a particular voltage source like V 1 or V in in this case and we want and for some downstream use we do not want to use this voltage, but a smaller fraction of that we can easily do that using a combination of these 2 resistances. And their relative values that is a ratio of this R 1 plus R 2 like if we write this one as something like 1 plus R 1 upon R 2 by contouring the ratio of these 2 resistances R 1 upon or R 2, we can easily control the ratio of this V out and V in and that is called a voltage dividing circuit and it has a huge amount of practical application in several cases.

Like you may have heard about a name of ballast resistor which is nothing but a voltage dividing circuit the bridge circuit which 1 (Refer Time: 11:57) that we have discussed in the previous lecture that is actually a combination of 2 such voltage dividing circuits.

So, we can easily by changing the ratio of this R 1 and R 2 or R 1 upon R 2 we can easily get a particular fraction of V out from V in. However, in practical cases of course this output voltage we have to measure using a voltmeter which may have some finite resistances and therefore practical circuit may look like this, where this R L actually is the resistance corresponding to a load or in this case the resistance internal resistance of the voltmeter which we are using to measure the V out.

This is very just in the next lecture which will be coming in the next week which you will be using this particular circuit for measurement of displacement, something known as the potentiometer, this is very much a potentiometer circuit with a voltmeter of internal resistance R L.

Now, we have to check how much error the presence of this R L is introducing into the magnitude of this V out, because V out is the one that we are truly trying to get, like in case of a potentiometer used for displacement measurement V out should be proportional to the displacement. However, the presence of R L may cause some error in the magnitude of V out and that we have to check here.

So, let us consider I is the current that is flowing through the primary circuit and I L is the current that is flowing through the circuit R L, therefore the current which is flowing through this R 2 is nothing but I minus IL. So, let us first calculate the equivalent resistance of these 2 parallel resister, that is R 2 and R L we know that this will become R 2 into R L divided by R 2 plus R L. And therefore we can write V 1 to be equal to I into corresponding resistance of the corresponding equivalent circuit that is R 1 plus R equivalent that will be equal to V 1 or I should be equal to V 1 divided by R 1 plus R equivalent.

Now, we have to calculate R L let us call this particular point as A and this particular point as B as both R 2 and R L are connected between these 2 points. So, the voltage drop across these 2 resistors has to be equal using that principle we can write IL R L the whole potential drop across R L should be equal to the potential drop across R 2 that is I minus I 2 sorry I minus I L here I should write this properly it should be I L, I minus I L into R 2 from here I can write this to be as your V out or V AB as far our notation.

So, using this I L using the equation becomes equal to R 2 by R 2 plus R L into I, hence V out will be equal to I L into R 2 which we are trying to measure or sorry I L into RL because R L is our internal resistance of the voltmeter and I L R is the potential drop across this which you are going to get as the final output. So, your I L is R 2 by R 2 plus R L into I into R L this plus R 2 R L by R 2 plus R L into I, which is nothing but R equivalent and this I can be related to put in the expression for I we can write this one as V 1 by R 1 plus R equivalent for I into R equivalent which gives you V out by V 1 to be equal to R equivalent by R 1 plus R equivalent.

Now, just to distinguish between these 2 expression, let us call this V out to be o that is for open circuit or no load condition and this is V out c for closed circuit condition. So, the error that gets introduced here should be equal to V out in case of open circuit minus V out in case of a closed circuit. And we have to combine these 2 expressions, this expression that we have got here and this other expression that we have got and put the expression for R equivalent and if you put it then just directly by simplification it will be coming as R 2 into R 1 1 plus R 2 upon R L plus R 2 this to V 1 or actually I should not write this way truly speaking I should have done this directly.

So, this is your expression for either just for simplification purpose we can write this as here this V out c that once you simplify it will be coming to be equal to R 2 into R 1 1 plus R 2 upon R L plus R 2 into V in.

If we compare this one with this expression then you can see when this R 2 upon RL tends to 0 V out for the closed circuit that is with the voltmeter tends to V out correspond to the open circuit that is the true voltage that we are trying to measure. Therefore, it is very certain that we need to have R L much much greater than R 2 like something we have discussed in the previous lecture itself, the resistance internal resistance for the voltmeter has to be extremely high to get any kind of realistic measurement or to reduce this error to a very small value.

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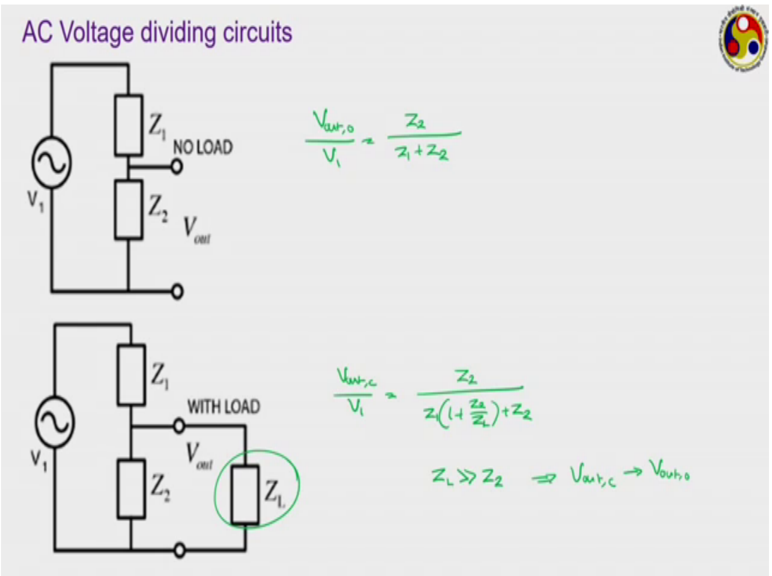

This is for DC voltage division we can have similar AC voltage division circuit just the way we have created the (Refer Time: 18:54) bridge or corresponding AC bridge circuits in last class. Just the same thing we can do just replace all the resistances with corresponding impedance values like here we have Z 1 and Z 2 as the 2 impedances for a know for a AC voltage dividing circuit with at the absence of any load. Very simply we can write that V out for the open circuit condition divided by V in will be equal to here Z 2 upon Z 1 plus Z 2.

Whereas when there is a closed circuit situation in this case V out closed circuit by V 1 is finally going to become Z 2 by Z 1 into 1 plus Z 2 upon Z L plus Z 2. Where Z L is the impedance of this corresponding AC voltage internal impedance of the AC voltmeter that you are going to use. So, the same principle valid here Z L has to be significantly larger than Z 2.

So, that we can have the output voltage in the closed circuit combination to approach the output voltage correspond to the open circuit condition. Rest of the calculation procedure remains the same and this is the way we can easily get a fraction of this V 1 as the output voltage, both in case of AC and in case of DC.

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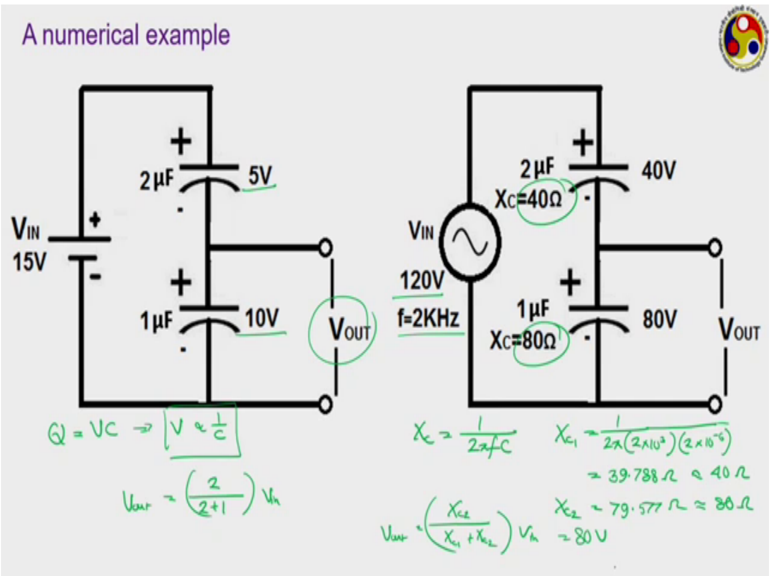

This is a numerical example of the same, here we have couple of capacitors they are connected in series and we have to measure the output voltage which is across this second capacitor of 1 microfarad versatile and input voltage is DC 1 just 15 volt. Now, for a capacitor we know that the charge across the capacitor Q is equal to V into C. So, applying the same principle or we can say for a given value of Q V is inversely proportional to C.

So, if we assume same charge for both the capacitors of 2 microfarad and 1 microfarad, then in this case Z 1 plus Z 2 is equal to 3 microfarad generally do not write this way. I should say this we generally do not write or add up the capacitors for the capacitors this way as that is not a proper representation. So, instead of that we can directly make use of this particular relation as voltage is inversely proportional to the capacitance.

So, it is very logical that the voltage across the 2 microfarad capacitance should be smaller compared to that one corresponding to 1 microfarad. So, using just common sense we can say that this one will be equal to 5 volt and this one will be equal to 10 volt and we can easily calculate the output voltage to be equal to 10 volt or we can say this V out will be equal to as they are inversely proportional 2 divided by 2 plus 1 of V in which gives you this 10 volt.

Whereas if you are talking about an AC source again the same situation we have 2 capacitance of 2 microfarad and 1 microfarad value, but here your voltage using AC with a mean of 120 volt and frequency of 2 kilohertz, so you have to calculate the output corresponding to this. So, for that we have to calculate the corresponding impedance and we generally know that for X c is given as one by 2 pi f into C.

So, for the first one X c for the first one there is one corresponding to microfarad if we put the values 1 by 2 pi frequency of 2 kilohertz, so 2 into 10 cube into capacitance is 2 microfarad. So, 2 into 10 to the power minus 6, so if you put the values it is going to be coming as 39.788 ohm which can be approximated to be equal to 40 ohm as shown here.

Similarly, X c 2 just the same we can calculate only we have to put C equal to 1 microfarad that is 1 into 10 to the minus 6 that will be coming to be equal to just develop the previous 1 79.577 ohm or approximately 80 ohm which is shown here.

So, the one have so corresponding given resistances are 40 ohm and 80 ohm, so your V out will be equal to X c 2 divided by X c 1 plus X c 2 into V in and here X c 2 is equal to 80 X c 1 plus x c 2 is 120, so that will be equal to 80 volt or 2 3 rd of 120 volt. So, this way we can define discuss or we can use the voltage dividing circuits for any kind of measurements.

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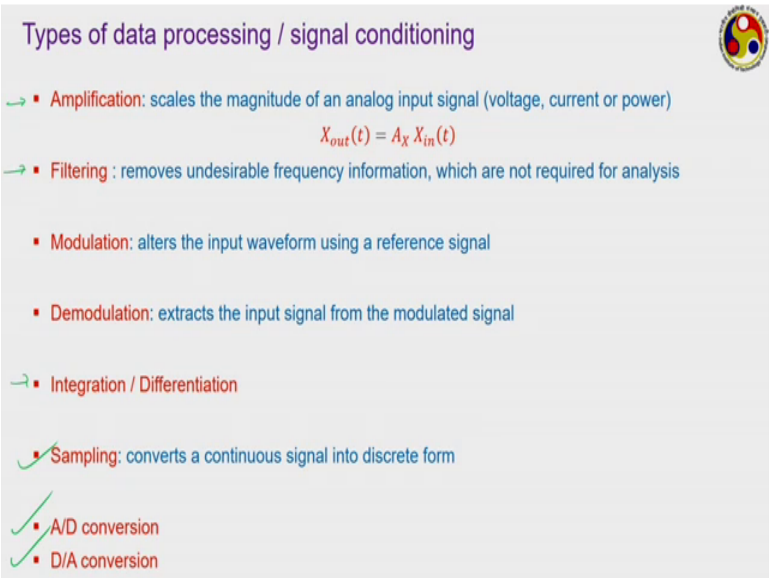

Now let us quickly move to the data processing or signal conditioning, using this analog instruments or even in case of digital instruments also we can modify the processed data into some form which is suitable for us and for that we may have to go for several kinds of data processing.

All of them may not be applicable in the same situation, but some or 1 or more than 1 data processing options we often have to use in different kind of situations and the most important 1 of them is the amplification. Amplification refers to the scaling the magnitude of an analog input signal generally scaled to a higher value.

But some situation if you have to scale it to a lower value as well and this input signal generally is an electrical one like voltage current or power situation in we have a relation like this. Where the output is multiplied by the input by a factor A x where A is called the amplification factor or the gain of the device here x can refer to voltage current or power.

Filtering is another one which removes the undesirable frequency information's which are not required for the analysis and maintains only the zone of in frequency information's which are relevant for the analysis. Modulation refers to the alteration of the input waveform into using a reference signal to a form that suits our requirement and demodulation is just the opposite one which is recovering the original input signal from the modulated version.

So, all these filtering modulation demodulations we have to use in case of AC signals, but amplification is useful in case of both DC and AC. Integration and differentiation just their name suggests which it often we have to make use of like just think about. If we think about say velocity it is and we have information available about the displacement or this variation in displacement with time then differentiation of that is going to give you the velocity.

So, in case of velocity or acceleration measurement we quite often we make use of this integration sorry the differentiation option. Whereas the integration option you can often find in case of the counters, like in vehicles you have often found that there is a meter which indicates how many kilometres your vehicle has put in and that is nothing but the integration of the velocity over time. So, these integrators and differentiators have very important use very common use in several situations.

Sampling we have discussed sampling in the previous week which where we convert a continuous signal into a discrete form and corresponding analog to digital or digital to analog conversion. Out of these this sampling and these 2 conversions we have already discussed in the previous class, let us quickly discuss about this amplification filtering and very briefly about the integrator and differentiator. Modulation and demodulation we are not going to talk about here because there they require in intricate knowledge of electronics.

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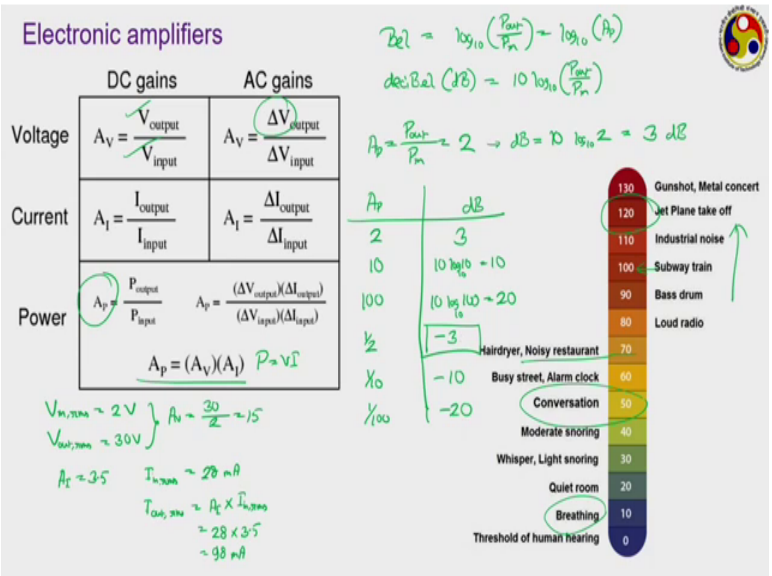

So, electronic amplifier as I have mentioned can have both DC and AC operation and can use voltage current or power anyone as the input. Like if you are talking about voltage amplification then the gain or amplification factor is defined as output voltage by the input voltage same for current or power and as we need know that the power can be represented as a product of voltage and current that is we can write P is equal to VI. So, correspondingly this power amplification factor can be represented as the product of voltage and current amplification factors.

Whereas if you are talking about AC then we generally use this symbol delta which refers to the change, the change in output voltage divided by the change in input voltage gives you the AC voltage gain. Gain has can be calculated using output input information or vice versa means output value can easily be calculated if you know the gain.

For example, suppose for an AC voltmeter it is given that your input voltage or I should say the RMS value of the input voltage is 2 volt and the output is measured to have an RMS of 30 volt then we can easily calculate the corresponding voltage gain for this AC amplifier as 30 by 2 is equal to 15.

In the contrary in a certain situation suppose it is given that in a particular current amplifier the amplification factor is 3.5 and we are providing an AC input current with an RMS of 28 milliampere. Then we can easily calculate the RMS for the output current as the gain into the AC value or input value which is 28 into 3.5 which is going to whatever you are getting, I think it is 98 milliampere and that is going to come. So, we can easily get the values if we know the gain.

How to measure the value of the gain? Quite often we make use of the unit Bel or I should say in earlier days the unit Bel is to get used where for power amplification that is for this AP, this Bel is defined as log base 10 of P out by P in or log base 10 of this AP. This particular definition of Bel or the name Bel was in honour to Alexander Graham Bel. Of course, you know the name the inventor of telephone and numerous other commonly devices this Bel came from his name.

But a problem with Bel is that it is too large unit for practical purposes. So, we shift later 2 decibel or in short dB small d capital B which multiplies Bel with 10 and defines this as 10 to log base 10 of P out by P in. You have to remember the base of the logarithm it is not natural logarithm rather base 10 that we are using, this is the most common unit for measurement of any kind of signals particularly any kind of amplifications you definitely have heard this term decibel and this is the way we represent this one.

It is a logarithmic scale very similar to several other common scales like you must have heard about the Richter scale which is associated with measurement of earthquake that is a logarithmic scale as well. Like a 10 times a sum value of 6 on Richter scale refers to an earthquake which is 10 times stronger than earthquake with the Richter scale value of 5, but 10 times less stronger then an earthquake of earthquake of 6 7 Richter scale reading.

Similarly, the chemical ph scale that is also a logarithmic scale, so decibel allows us to measure the value of amplification in terms of a logarithmic scale. There are couple of very big advantages of using this decibel notation that is we get much smaller numbers to deal with and also we can easily add different stages of and presence of gain from of an electronic circuit, just by performing simple arithmetical addition.

We can this is just a common scale of different kinds of decibel values that we get, like our common activities will breathing corresponds to very low decibel value of 10 whereas our general conversation can often go up to 50. A noisy restaurant can go up to 70 this is something which is suitable for common human ear that is 65 to 70 is generally the permissible decibel limit for most of the countries. Because everything above this corresponds to high noise, like loud radio subway train can go up to 100 and jet plane taking off go to 120 which are extremely high level of sound that we are talking about.

Now, decibel being a logarithmic scale so quite often we have to convert the gain into these values, like suppose if we are talking about an amplification factor that is power amplification P out upon P in to be equal to say 2, there is output power is 2 times the input power, then corresponding decimal value will be equal to how much? 10 into log 10 base 2 that is equal to approximately equal to 3 so it is only 3 decibel.

Whereas, if we make a table kind of thing, whereas it is 2 this becomes 3 when you go to 10 then we have to deal with 10 log 10 base 10 which gives you 10. Whereas, when this becomes 100 we have 10 log 100 base 10 that is just equal to 20. So, when the gain becomes 100 times our output power is 100 times stronger than the input power signal the decibel value will become 20.

Similarly, if your gain is half then it will be just minus 3 because, that means when the output power is half of the input power we can represent that to be is decibel of minus 3, it is equal to one-tenth this becomes minus 10. When it is 1 upon 100 this becomes minus 20 these are you can easily convert from the gain value to the decibel value minus 3 is minus 3 dB is of particular importance, because quite often this one is used to characterize frequency response of amplifiers.

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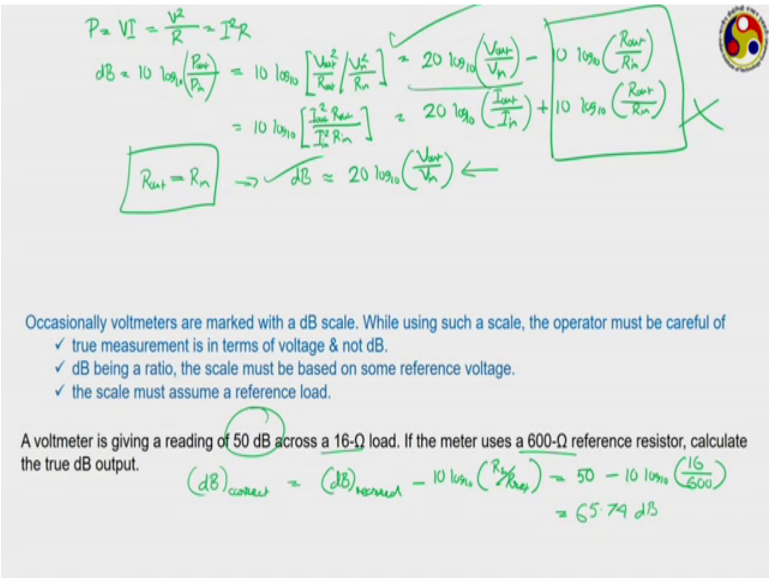

Now, for a pure resistance we know that P is equal to V into I or we can write this one as in 2 ways we can write this one as V square upon R or we can write this one as I square R. Now if we want to write this on in terms of decibel values there are 2 way we can write we know that decibel is 10 log 10 P out by P in.

So, if we take the first definition that is V square upon R then we have 10 log 10 into V out square by R out divided by V in square by R in, which gives us 20 log 10 V out by V in minus 10 log 10 R out by R in or if we take the current definition then this will become I out square R out R in that is 20 log base 10 I out by I in plus.

So, this way we can have 2 alternate definitions of the decibel value or gain in decibel in terms of either voltage or current, in several situations we generally neglect the presence of this R out or R in or I should say the difference between R out and R in that is. If the resistance of the output side is equal to the resistance of the input side then we can neglect this portion and leaving out only this; that is in several situations we can have the dB is given approximately equal to 20 log base 10 of V out by V in.

But that is possible only when we have this particular thing satisfied, otherwise that may introduce significant error in your measurement. That is the output side impedance of your voltmeter and input side impedance of the voltmeter should be of the same order very close to each other otherwise we cannot use this particular value, we often have to go to the we have to go to the original definition like this.

But unfortunately in several situations you will find this is the definition of dB that is given, but that inherently considers did for this particular assumption. Occasionally voltmeters are marked with a dB scale that is instead of giving in terms of voltage voltmeters which also incorporate an amplifier within it they are marked in terms of dB. Whenever you are trying to use such a scale the operator must be very careful that the true measurement is not of decibel, but of voltage that we have to remember.

Secondly, dB is a ratio that is the output to input power ratio or voltage ratio in case of voltages. So, we have to be careful about what reference it is using and thirdly the scale must assume a reference load so that it can make use of this particular condition. So, this is something the operator has to be very very careful of, like one numerical problem we can check out to check the effect of this resistance.

Here we are talking about a voltmeter which is having a reading of 50 degree across the 16 ohm load, if the meter uses 600 ohm reference resistor calculate the true dB output. That is it is giving you an output of 50 decibel across a resistance of 60 ohm and during calculation we have neglected the presence of this presence of this or I should say not the presence we have assumed R out and R in to be equal, but practically speaking one is 16 ohm other is 600 ohm the reference. So, we have to calculate the correct dB by considering this.

So, the correct value of decibel or correct value in decibel will be equal to the one measured which is nothing but this particular thing minus 10 log base 10 R for the load divided by R for the reference and the one that is given is 50 dB the reading given it is minus 10 log 10 into 16 ohm is a for the load and 600 ohm for the reference. So, if you calculate this will be coming to be 65.74 dB which is significantly different from what measurement value that is got. So, we have to be very careful about the equality between the reference and the load resistor.

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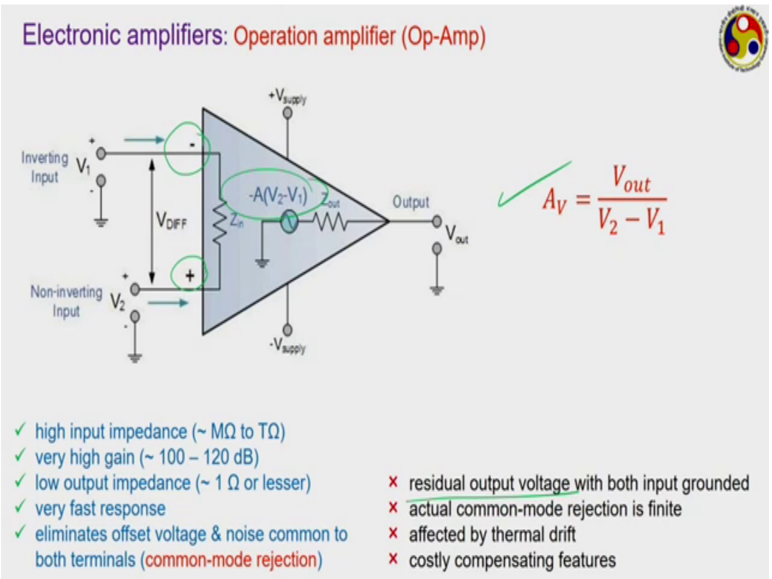

But with this knowledge we can move on to a few amplifiers and this is the most common kind of amplifier you will find in electronic circuits which is called the operational amplifier Op Amp in short, in Op Amp we general we use 2 different inputs to get a differential output. So, one of the inputs which is called non inverting is connected to the positive terminal other is inverting connected to the negative terminal. So, that the difference between these 2 voltage that is V 2 minus V 1 that is the one that gets amplified and we get the gain is like this, output voltage divided by V 2 minus V 1.

It has several advantages like very high input impedance we can get which can range from mega ohms to even tera ohms that is 10 to the power 12 ohms very high gain 100 to 120 dB is not uncommon with this Op Amps low input low output impedance that is another advantage. So, which can be 1 ohm or even less very fast response we can get from this and it eliminates offset voltage or noise common to both the terminals which is commonly known as the common mode rejection they are by providing a noise free output.

However there are a few disadvantages also like residual output voltage with, when both the inputs are grounded, it still can give you some output voltage it is known as the residual output voltage and the which require certain kind of processing or fixing or some kind of modifications in the design, so that we can get purely 0 output with 0 inputs.

Actual common mode rejection can be finite and there can be error introduced under certain situations affected by thermal drift because, each of the components present inside the amplifier are affected by the change in temperature and therefore there can be strong effect of change in temperature on the final gain. And if we are using any compensating device like to compensate for the thermal drift to compensate for the residual output voltage or common mode rejection the cost keeps on increasing very rapidly.

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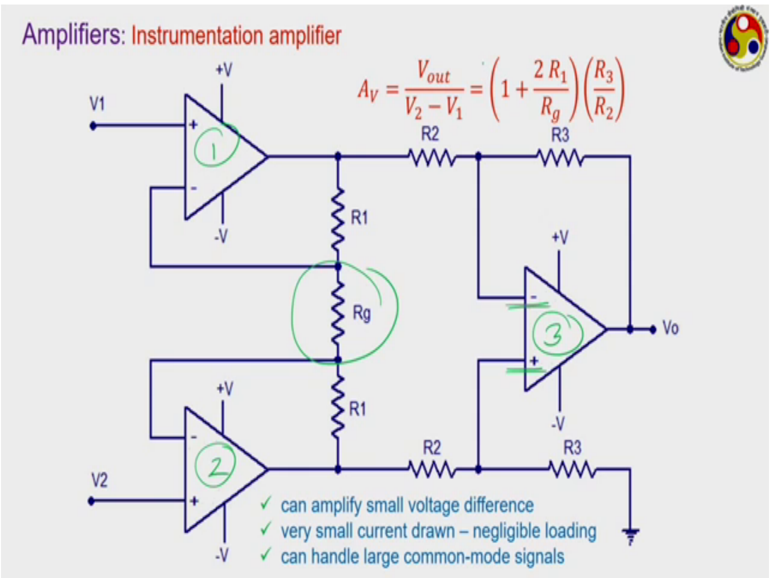

And there is another one that is called Instrumentation amplifier which actually combines 3 Op Amps, this is number 1 this is number 2 and this is number 3 1 input is supplied to the one amplifier 1 and second input supplied to amplifier 2 and both of them are connected through this ground resistors. And then the output obtained from both these Op Amps are connected to this third amplifier this one acting as the non inverting one this one acting as the inverting one.

Instrumentation amplifiers are particularly useful when you are talking about amplification of very small voltage difference between V 1 and v 2 and also it generally it was very small amount of current. So, negligible loading effect or loading error we get the output and we can it can handle large common mode signals through this internal circuitry the common mode signal gets cancelled. By using simple analysis of electronic circuits we can get this expression for the gain for instrumentation amplifier.

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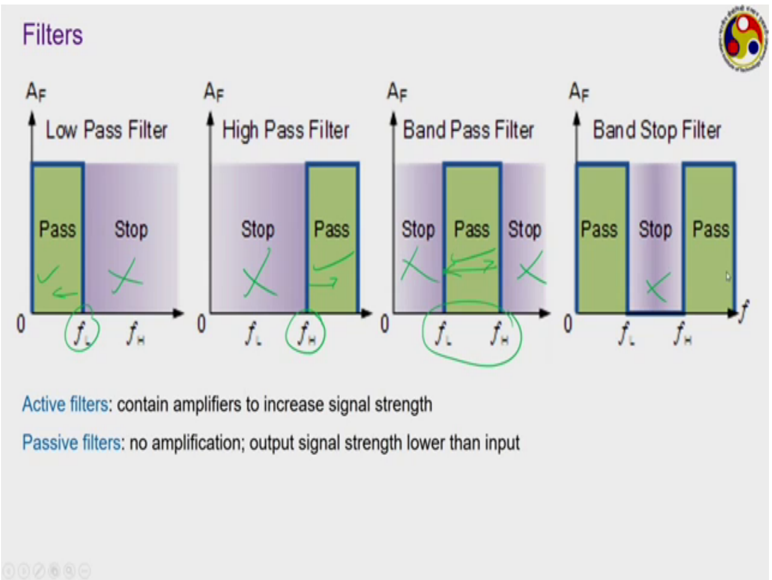

Next we have Filters, filters refers to a device which allows us only the frequency which we need to go to the output side and completely stopping any output which we do not want. Like low pass filter refers to which allows all the frequencies below a particular one to go through, higher ones cannot go high pass filter is opposite, beyond a certain critical value it allows everything to go through and stopping everything below that band pass in an interesting combination of these 2 which allows frequencies within only a certain range to go through and nothing on both sides are allowed and band stop is just opposite of band pass where within a certain band frequencies are stopped outside frequencies are allowed.

We can also define or classify filters into active and passive categories active means it contains an amplifier along with the filtration, whereas passive case no amplification done output signal strength generally is lower than the input because several frequencies are cut out from this.

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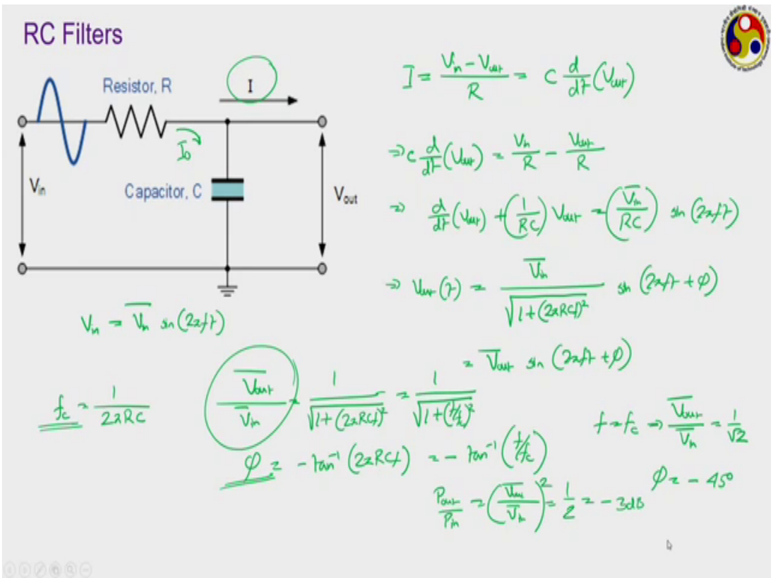

Filters can be formed by suitable combination of resistors capacitors and inductors and RC filter refers to combination of resistor and capacitor, just look at the one that we have. Here the input signal is directly supplied to the resistor and the capacitor is connected in parallel.

So, I is the current that is flowing through this let us see I 0 is the current that is flowing through this circuit and if the current drawn at the output side this I is negligibly small, then we can write this I to be equal to V in minus V out divided by R and this can using the definition of a capacitor this can also be related to C into d dt of v out. So, if we combine this V out will be equal to V in upon R minus V out upon R sorry C is also there. That means, d dt of V out plus 1 by RC of V out is equal to 1 by RC of V in.

How this relation looks like here V in is the input V out is the output R and C these are system level parameters so this is a very simple first order equations. From whatever we have discussed earlier from there you can easily calculate the time constant and steady state gain for the circuit. But that is generally not our objective in objective here, most oftenly this circuits are subjected to or as this circuits are subjected to AC inputs.

So, let us form let us assume that the form for V in is something like this, V in bar to sin 2 pi f t where this V in. However, represents the mean and f is the frequency. Then we are going to have this one replaced by V in bar sin 2 pi f t and we have to solve this equation. Instead of directly solving this we can use our concept from the second week of this course from the second module and from there we can write directly that is this V out as a function of t from the solution will be of a form like V in bar into root over 1 plus 2 pi RC f whole square sin 2 pi f t plus phi or we can write this one to be V out per bar sin 2 pi f t plus phi. Here V out bar is the mean of the output signal divided by V in bar is equal to 1 plus 2 pi RC f whole square.

Generally we define a corner frequency f c as 1 by 2 pi RC or critical frequency is more commonly called. So, it can be written as tau bar 1 plus f upon f c whole square, on the other side the phi the phase lag can be related to minus of tan inverse 2 pi r c f that is minus tan inverse of f of 1 f c. So, this so you can easily calculate the output voltage characteristics of a simple RC filter for this particular design as well.

There are several other combinations possible where we can have capacitor first and a resistor second or a different kind of orientations, but always it is critical to identify this critical frequency or often called the cut-off frequency because, both the ratio of output to input amplitude or amplitude ratio and the phase lag depends upon the magnitude of f c.

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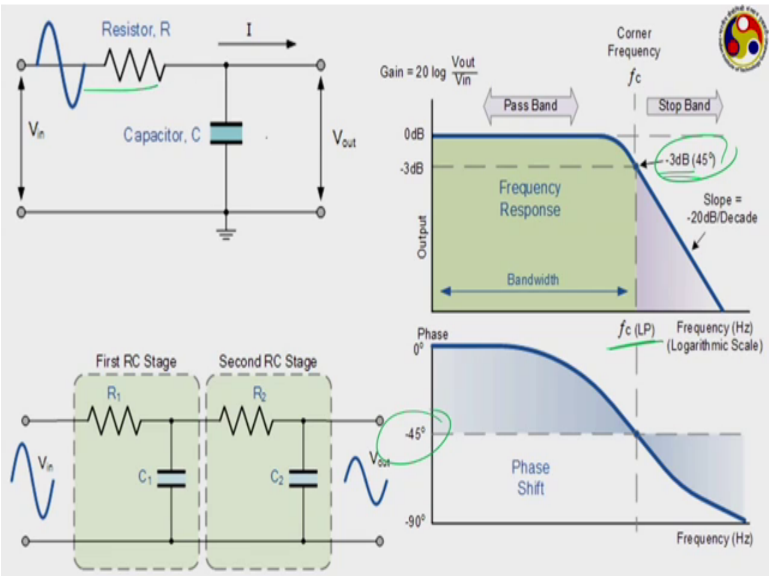

This is the one that we have just analyzed this is actually a low pass filter. The corresponding representation you will be getting like this, this is the value of f c till this f c you can find there is only minus 3 dB reduction in this and it does not allow anything to pass beyond that value of f c.

But any frequency value less than this is have to go through and corresponding if we just go back to the previous circuit, when f becomes equal to f c that is when we have reached this cut-off value then what we have your V out by V in or I should say V out over bar by V out over bar should be equal to 1 upon root 2 and phi should be equal to minus 45 degrees.

So, if we check in terms of powers P out upon P in we know in terms of decibels, we can relate this one to be if assuming equal resistances this can be equated to V out bar over square by V in over bar square that is equal to half that is minus 3 dB and the same thing we can find here it is minus 3 dB reduction corresponding to a phase shift of minus 45 degrees. If required we can combine several RC stages to reduce even further frequencies, just look at the orientation area of resistor first and then the capacitor.

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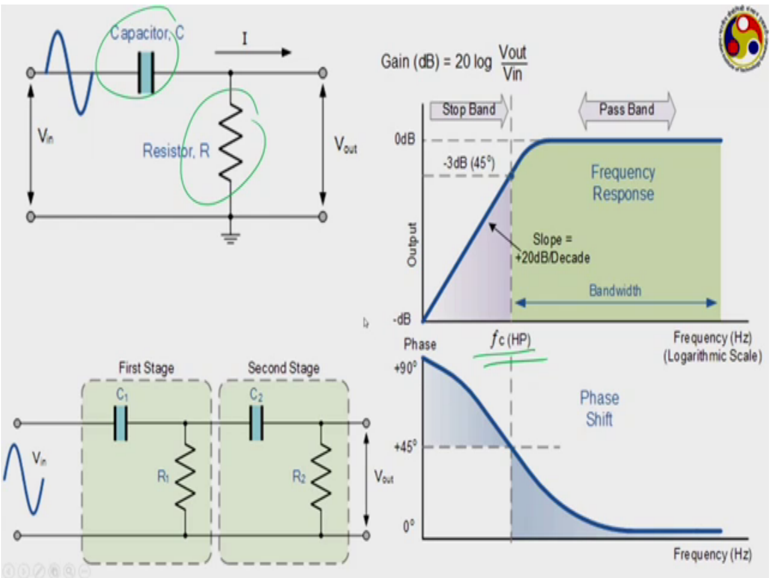

If we change this capacitor first in the line resistor in the parallel circuit we have a high pass filter, everything below this f c they are stopped and the frequency after that are allowed here also you can have such combinations and when you combine these high pass and low pass filters just like this.

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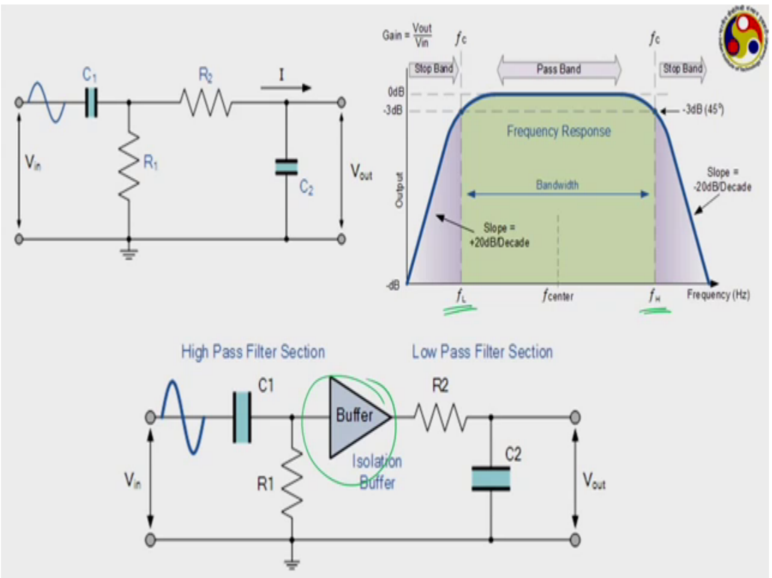

Then we have a band pass version where we have 2 cut off or critical frequencies 1 f L other f H, anything below f L or above f H are not allowed to go through. But frequencies in between are allowed to pass and sometimes we put an isolation buffer in this, is an example of an active filter which we are not going to discuss any further, where along with the band pass option we are getting the amplification of the signal as well.

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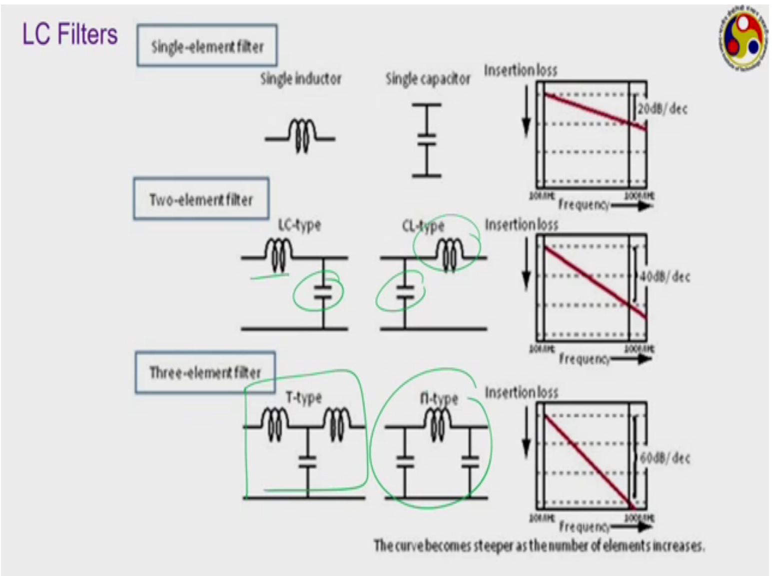

Earlier we had RC filters similarly we can have LC filters or R L filters as well, LC filters you can see there is a combination of an inductance and the capacitance or capacitance first inductance second, we can have multiple such kind of T or n kind of see a circuits as well, each one has its own way of operation.

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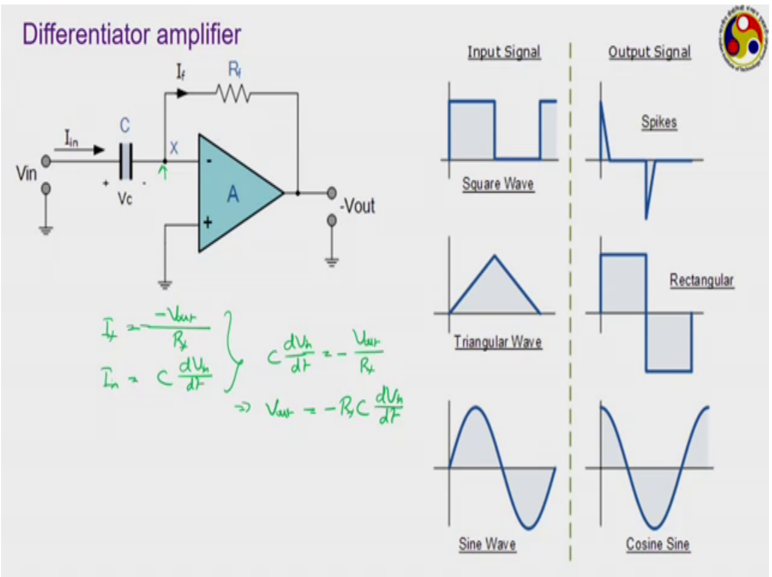

So, this is about filters, this is a differentiating circuit just look at how the circuit is operating, here we have a capacitor in the input line and resistor parallel to this amplifier. So, if they are operated properly there is the current I in and I f will be equal to each other, so that the voltage of this particular point x is equal to 0. So, if we consider the resistor part then I in or if we consider first the resistor part then we can write the current I f should be equal to minus of V out by R f or it should be actually V x minus V out by R f, but V x be equal to 0 we can remove this. So, it is minus V out by R f.

Similarly, I in can be defined as C into dV in dt following the definition of the capacitor and as these two are equal to each other. So, we have C dV in dt is equal to minus V out by Rf or V out is equal to minus R f C dV in dt that is output voltage is only a differentiated version of the input voltage, these are certain examples. For a square wave input you are getting only spikes, whereas in case of a triangular input you are getting a rectangular output. For a sine wave input even more interesting we are getting a cosine waves by simple method differentiation you can always get all these output signals.

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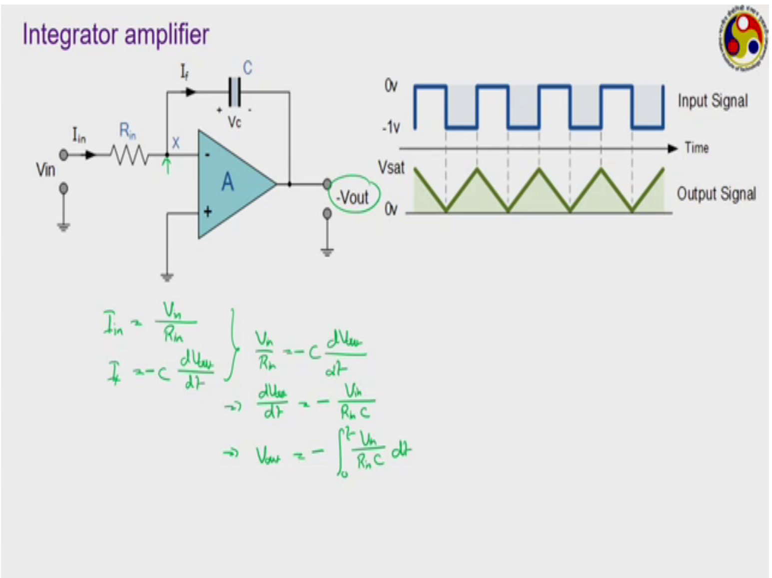

Just the opposite of this it is a integrated circuit, where is the resistance in the male line and capacitor in the bypass line to this amplifier. So, again here a voltage at the point x is equal to 0 and I in an I f are equal to each other. So, your I in will be equal to V in upon R in and I f will be equal to C into dv out dt or minus because there is a minus sign here.

So, if we equate these two then we have V in upon R in is equal to minus C into dV out dt, that is dV out dt is equal to minus of V in upon R in C or V out will be equal to minus of integral 0 to t V in by R in C dt. So, it is an integrated form, the output signal will be an integrated version of the input signal, like we shall be discussing about this circuit in our week number 11 slightly more or at least the application of such an integrator and differentiator when we shall be talking about the measurement of display measurement of velocity and acceleration. This is an example of the application of a integrated circuit.

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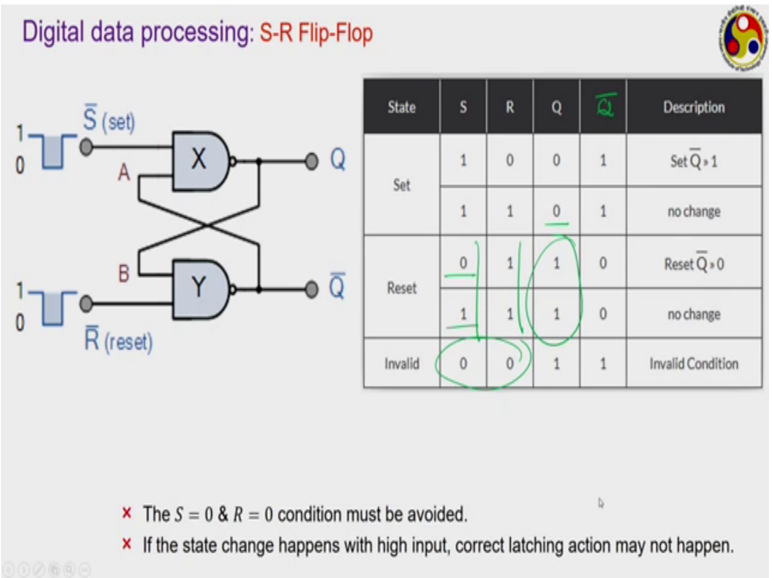

So, this takes us towards the end of our discussion of analog data processing, for digital data processing as it was initially included in the syllabus for this course actually very very briefly we mentioning about the flip flops. I am not at all going to the detail of this and you may keep this next couple of minutes of discussion. But if anyone is interested you can check further documents on any standard electronics books to know about flip flops.

So, one of the most important component of digital data processing are this SR flip flops. Actually one very important component of digital representing we have already talked in the last class in the form of the logic gates and their combinations. Flip flop is no separate, you can see you can easily identify the nature of this X and Y and here you are giving 2 inputs 1 is S other is R there. So, they are called SR flip flops, one is set other is reset kind of inputs and when S is set to 1 R is set to 0 you are going to get Q equal to 1 and Q bar is equal sorry Q equal to 0 and Q bar equal to 1. So, this 1 should be equal to Q bar just somehow missing.

And now when we check change this R 2 1 that is we reset the circuit Q is still become 0, as soon as there is a change that is S becomes 0 it continues to be 1, but when S again becomes 1 it continues to be 1. But both are 0 that is not a valid condition one of the biggest disadvantage for the SR flip flops.

By using this combination if you have understood the logic gates properly you can easily form these data tables, but the idea is that as long as a reset is not modified the final output remains the same, like initially you were reset continues to be 1. So, a change in the S value does not alter the value of this Q, but problem with SR flip flop is both 0 conditions must be avoided and if the state change happens with high input correct latching action may not happen.

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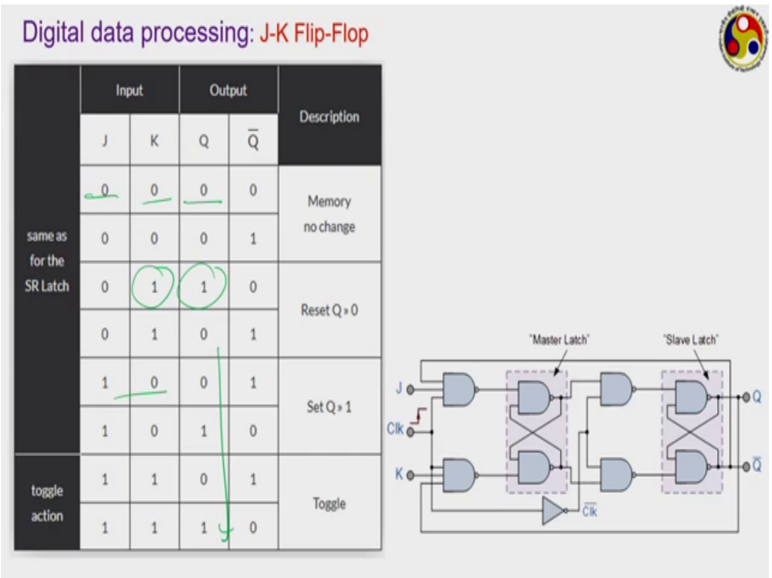

	Input		Output		Description
	J	K	Q	Q̄	
same as for the SR Latch	0	0	0	0	Memory no change
	0	0	0	1	
	0	1	1	0	Reset Q » 0
	0	1	0	1	
	1	0	0	1	Set Q » 1
	1	0	1	0	
toggle action	1	1	0	1	Toggle
	1	1	1	0	

That is why people go for JK flip flops, in JK flip flop we have removed that option here we can remove that disadvantage here we can still have 0 0 kind of inputs so that you can give 0. When both are 0 there is no change in the memory output, however as soon as 1 becomes 1 there is a change and it does not change with resetting the Q to 0 and whenever Q is set back to 1 then you can see there is a change here and subsequently it keeps on changing.

This logic gate again you can form following the circuit of JK flip flop which I am not giving here because it is more complicated computation flip flop and such detailed electronic knowledge is not required in this particular course. But generally this is the way they are connected if you are interested you can explore this further.

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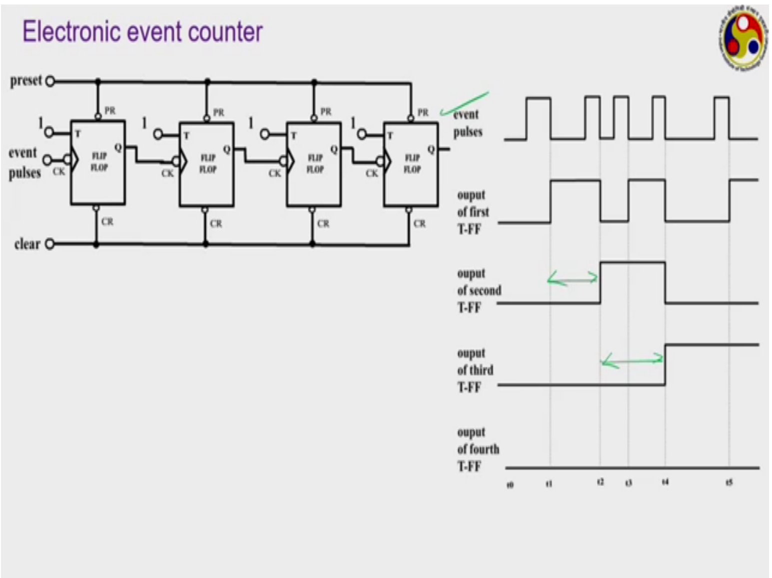

The application of the JK flip flop in the form of this electronic event counter. Now in your vehicles I mentioned that earlier also in your vehicles often you will find that distance meter, how many kilometres it has travelled, if that is an electronic one that actually count this way or you must have seen whenever you visit an website there are several websites which report some visitor count that is done principally by following a circuit like this.

This is it is just a combination of 4 JK flip flops connected like it is shown here and this is the output if the event pulse is something like this the output of the first stage will be like this, the second one will be delayed by this particular amount the third one will be delayed from the second by this amount and the fourth one will be delayed even further. And their combination will keep on giving you a count of the total number of event that has happened.

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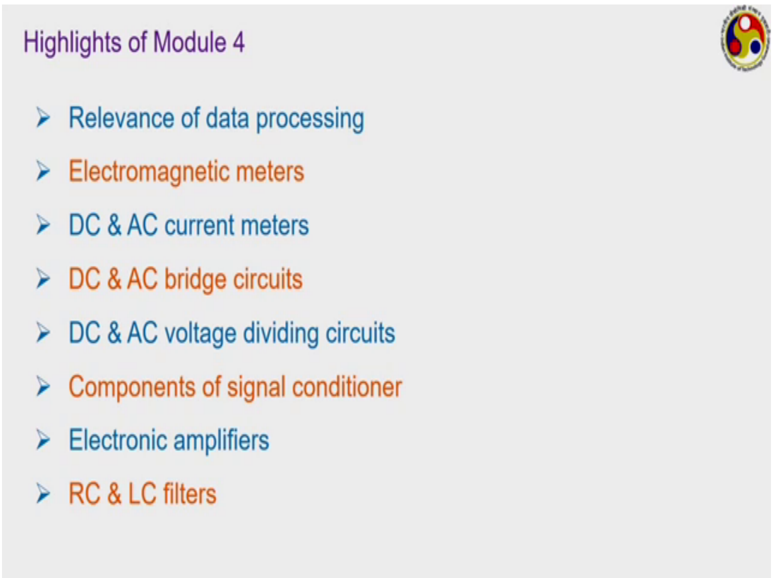

So, that takes us towards the end of this fourth module, this digital processing part we are keeping extremely short, it is only if someone is interested. But in this week we have talked about the relevance of data processing and we have seen that most of the components or measurement systems generally use an electrical output. So, we have talked in detail about the electromagnetic meter the D'Arsonval movement principle to measure electronic values or electric value of voltage and current in the form of DC and AC current meters. Then we have talked about the bridge circuits for measurement of impedances.

Today we have talked about the DC and AC voltage dividing circuits where we can get any output voltage or any fraction of the input voltage as the output using suitable combination of impedances. Then we have talked about different components of signal conditioners out of which electronic amplifiers are discussed in details particularly the RC amplifiers or I should not say RC amplifiers. Particularly the Op Amp amplifiers and then we have talked about the RC filters in detailed and just touching upon the LC filters and subsequently the differentiators and integrators.

So, that is it for this particular week I hope you have enjoyed it, there are several things that we have talked about, but just try to follow the principles of all those electric based devices or some bridge circuits that we have talked in and if in case of any query please write back to me. So, next week we are going to talk about the measurement of displacement till then goodbye.