Principles of Mechanical Measurements
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Lecture No. #12

So under amplifiers we have seen general characteristics of amplifiers with drift and noise and then AC amplifier and DC amplifier we have seen that is DC amplifier is obtained from the chopper amplifier. Now next two important amplifier is operational amplifier, it is also called op amp it's available in the market in chip form.

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This is nothing but a chopper amplifier with a high gain. So that is an operation amplifier, it's a basic building block for many circuits for example we can build from operation amplifier, integrators, differentiators by suitable feedback elements, capacitor resistance element with the operation amplifier we can obtain these integrators, differentiators. So another important usage of op amp is instrumentation amplifier it's often used in measurements. Instrumentation amplifier is obtained from a three operational amplifier or five operational amplifier there are built in circuit and they constitute instrumentation amplifier. It has got a special characteristic that it has got high input impendence and low output impedance and better linearity.

Hence we find an instrumentation is an amplifier which is obtained from operational amplifier by using a number of operational amplifier in circuit, it's made use of fully. So it's one of the important amplifiers operational amplifier. Next one is charge amplifier, the charge amplifier is widely used along with the transducers made up of capacitors, piezoelectric transducers. They have got the common property their output resistance is very high.

So when output resistance is very high, any instrument to read this output voltage the voltage output from these transducers should have ten times this resistance. So such an instrument or amplifier is not there, so piezoelectric crystal almost it is an insulator and so many mega ohms and a ten times this mega ohm you should have. So such ordinary amplifier may not possess very high input impendence, in such a cases we go for charge amplifiers. So main characteristic of charge amplifier is it's input impendence is very large, so when it is connected with piezoelectric transducer for examples so charge and voltage amplification takes place and we can make use of it. So charge amplifier is obtained again from operational amplifier, it's a built with a suitable feedback.

I think capacitor feedback is there for charge amplifier, capacitor feedback with an operational amplifier constitutes basic circuit for charge amplifier. The detail we need not go into that so that is charge amplifier main characteristics its input impendence is very large, so we go for usage with the capacitor, transducers and piezoelectric transducers. Next one is impendence transforming amplifier, actually it doesn't amplify the voltage but still it is called amplifier. The gain of this impendence and so amplifier is around one and less than one sometime but the main use is again such transducers, the output impendence is very large and suppose you don't have charge amplifier and we have to connect it to an instrument with a high input impendence is not available then solution is impendence transforming amplifier and so many amplifier say about two such versions are given there, one is tube circuit and another is the based upon the transistors. One is called cathode follower another is called an emitter follower but both of them are belonging to the impendence transforming amplifier.

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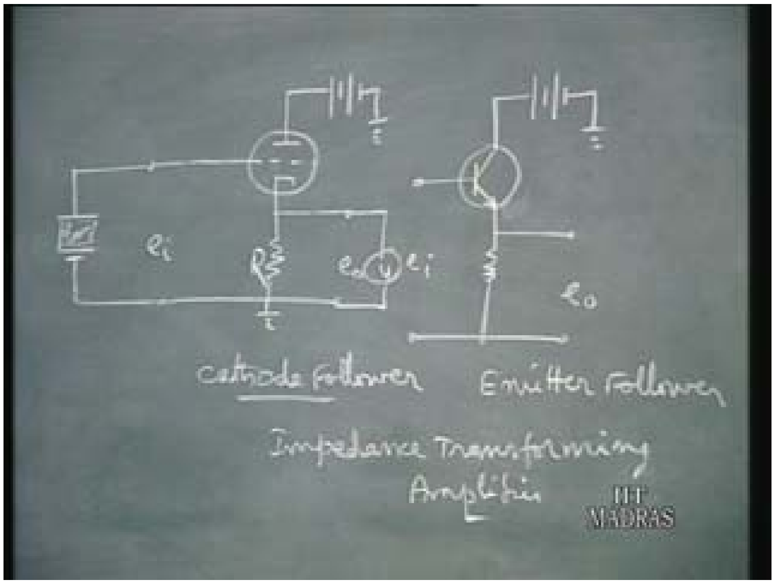

Input voltage is here you just check the input voltage, this may be the piezoelectric crystal so it is say for example it is connected like this, so it is insulating material so output impendence is very large and here also you will find grid and the cathode it is more or less open circuit.

That means here input impendence is very large so input impendence is large and large impendence circuit is converted into say this is R into an output impendent. Now the e_o is the output voltage from this impendence transform amplifier that output resistance is of the order of R, may be R of 100 ohms. So a high impendence, here it is high impendence circuit and here it is low impendence so these high impendence is converted into low impendence circuit by interposing an impendence transform. That is the main purpose of this amplifier. We convert a high impendence circuit into low impendence circuit. Later on we connect a voltmeter, this voltmeter may be of the order of 1000 ohm or 10000 ohm. Here it is 100 ohm only so 1000 ohm or 10000 ohm voltmeter are readily available.

So now you can read the voltage here, whatever is available with sufficient magnitude without further amplification we use it or if it is too low voltage we can interpose an AC amplifier and then amplified voltage may be read in the voltmeter. So that means when we don't have charge amplifier, we can substitute charge amplifier with a impendence transform amplifier plus AC amplifier both put together achieves the same functioning what we will achieve by using only a charge amplifier. Substitute for charge amplifier is impendence transform amplifier plus AC amplifier. So impendence that is main usage of the impendence transform amplifier.

Next one is the carrier frequency amplifier which is very important in measurements, carrier frequency amplifier. So very often used instruments wherever we have excitation voltage, here carrier frequency amplifier is somewhat like this. Now we see carrier frequency amplifier we find these applications in case of say strain gauge. So whenever we use a strain gauge they are forming part of the forum bridge, Wheatstone bridge and Wheatstone bridge has got four terminals against two terminals we are giving excitation voltage.

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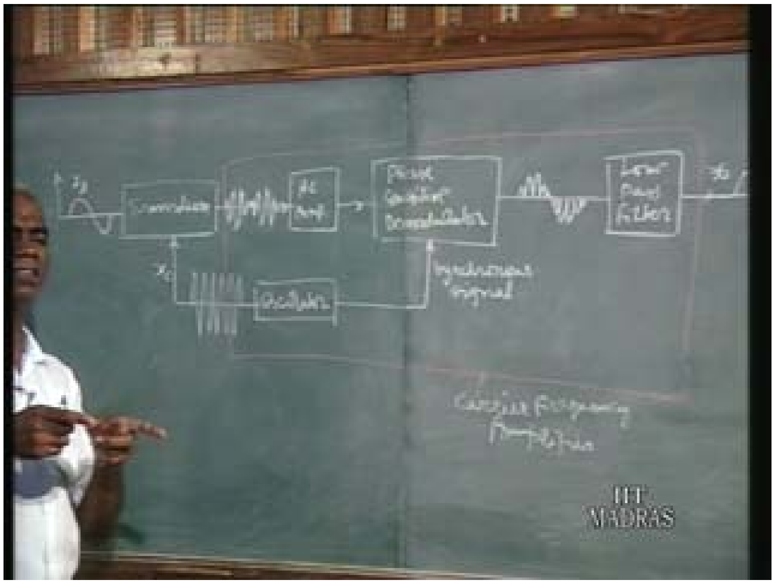

The other two terminals we take the output voltage and in such incidences the excitation voltage wherever you require such cases we go for the usage of the carrier frequency amplifier. Also when use inductive pick-ups later on we will be learning under displaced measurement and say it’s the inductive pickups, they also will be forming one or two arms of AC bridge, the AC bridge is to be excited that excitation voltage is located there, this gives excitation voltage plus amplifier.

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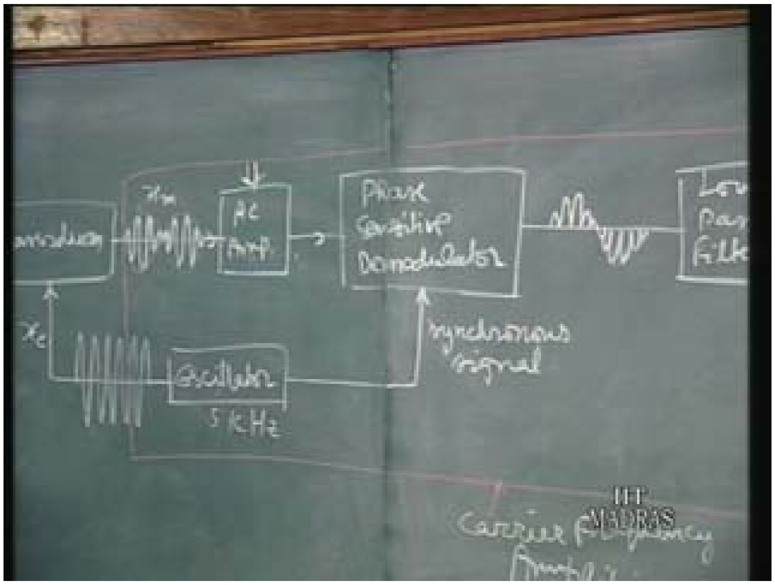

Hence such a applications we find very often carrier frequency amplifier. The principle is explained with these block diagram. We have got an oscillator mostly of the order of 5 kilo hertz frequency it’s a constant frequency and a constant amplitude signal. This is X_e we call it carrier signal and then we have got our desired signal this is our x_i our input signal i simply it renamed it as X_s signal desired signal this one and X_s and X_e are being combined at the transducer. This may be a Wheatstone bridge or some AC bridge so both the signals are combined. Here we have got so called an amplitude modulations, this is amplitude modulation that is modulated signal i will call it X_m. This is the amplitude is same as the amplitude signal and the higher frequency comes from carrier signal.

So previously we have constant amplitude now the amplitude is modified by the incoming input signal. So this is the X_m and now what we have done by this amplitude modulation? A slowly varying signal this may be of the order of few hertz 4 or 5 hertz and this is 5 kilohertz both of them when they combine we get another signal which is of the order of 5 kilohertz. That is frequency of the oscillator, near about that it will be there. We will see later what is actual frequency. So anyhow a slowly varying signal has been converted into a high frequency signal by the process of the amplitude modulation. Once we have got a high frequency signal it can be easily be amplified in an AC amplifier without any drift problem. If we want to amplify this then this frequency is much lower than the cut off frequency, it cannot be amplified here.

So by this process of modulation we converted the slowly varying signal in to the high frequency signal and then now we use the AC amplifier advantages without any drift. Here also it will be same but it is of higher amplitude because after amplifications this is amplifier, after amplification it will have a higher but same shape. Then later on we have got so called phase sensitive demodulator there we have got some synchronous signal. That is by using this signal and the phase difference between the carrier signal and the modulated signal, we can obtain the reversal here because here you will find modulated signal X is on both side positive and negative but here you find where the signal is there X_s is there.

The other side is brought this side so that now you have got the shape of the… So once after amplification our job is to extract the desired signal. The whole process is done to amplify this signal that is the process. By using carrier frequency amplifier you amplify the signal voltage but we cannot directly amplify here. So we use the modulation so after modulation we have got AC signal and now after amplification of AC amplifier our job is to extract the desired signal from the amplified signal. So this is a first stage, phase sensitive demodulator, the demodulation is the negative of the modulation process to extract the signal. So here we get this shape but it still contains high frequency signal even though the overall variation is desired signal but this high frequency content is filtered away by passing it through a low pass filter.

So afterwards you will find, you have got the output signal same as same shape and probably you have to draw little larger because after amplification we are getting, so with a larger amplitude we will have but if you don’t have so smooth signal but you have some ripples. Some of the ripples will be left over but still that will be of very high frequency but if you don’t note when we read it in an instrument because pointer may not follow such quick variations, so finally you have the overall change, only we will note. So that means we have amplified this signal by having this so called carrier frequency amplifier. That is a physical explanation how the carrier frequency amplifier functions but what is the mathematical treatment? See X_s now the amplitude modulation is nothing but a multiplication of the desired signal with the carrier signal.

So if we call modulated signal as X_m, X_m is equal to x_s desired signal into X_c carrier signal. Suppose X_s is A_s sin, it is sin function omega$_s$t that is our signal variation that is this variation into X_c, call it amplitude is A_c sin omega$_c$t. If this is the modulated signal now this can be written in a different way.

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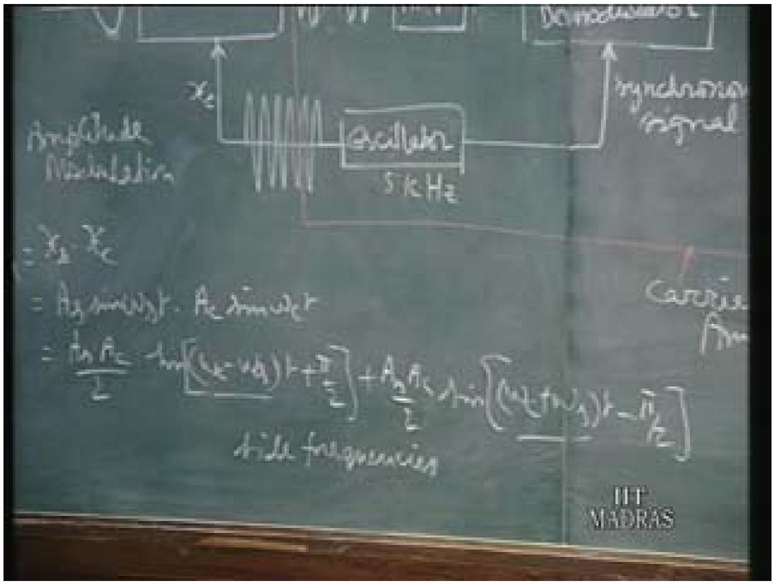

From trigonometry we can write it A_s into A_c by 2 sin of omega$_c$ - omega$_s$t plus pi by 2, so this is our sin term plus A_s into A_c by 2 sin of omega$_c$ plus omega$_s$ t - pi by 2. So this is the modulate signal. Now we find the modulated signal contains two side frequencies, these are the side frequencies due to modulation we have got two side frequencies omega$_c$ - omega$_s$ and omega$_c$ plus omega$_s$. So these are the two side frequencies.

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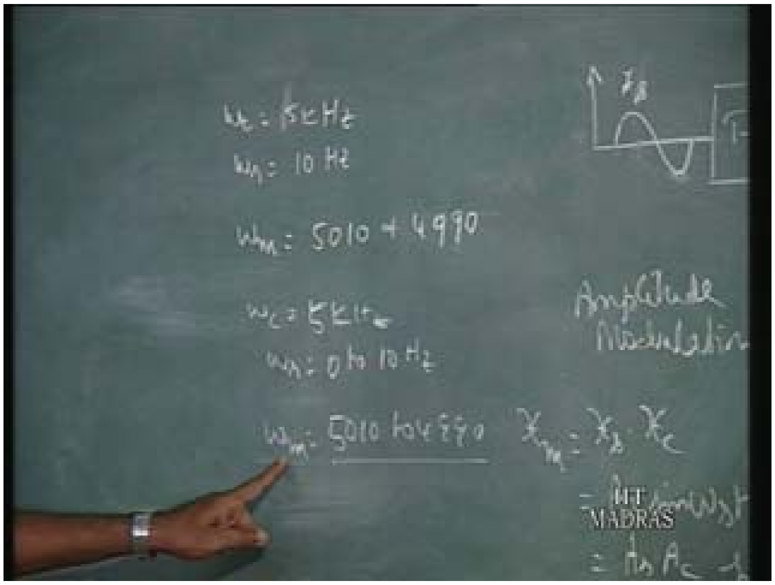

That means omega$_c$ is equal to 5 kilohertz in terms of kilohertz and omega$_s$ correspond to 10 hertz then modulated signal omega$_m$, modulated signal will be 5010 and 4990. These are the two frequencies of the modulated signal but we find it is very near the or it is varying around 5 kilohertz and suppose omega$_c$ is equal to 5 kilohertz and omega$_s$ is varying 0 to 10 hertz. If that is the case then omega$_m$ will be varying 5010 to 4990. So this is a variation but anyhow the frequency is around 5 kilohertz that is why we are able to amplify, AC amplifier cut off frequency is 100 hertz so it is very high then cut off value so AC amplifier amplifies the modulated signal. So these are the side frequencies.

As you have seen in the carrier frequency amplifier, a small varying signal is made into a high frequency signal where it can be amplified that is one of the main use of the carrier frequency amplifier. Secondly any disturbance from the transducer to the amplifier, suppose transducer is few hundred yards away from the amplifier and when the signal is passed from the transducer to the amplifier there may be some power line.

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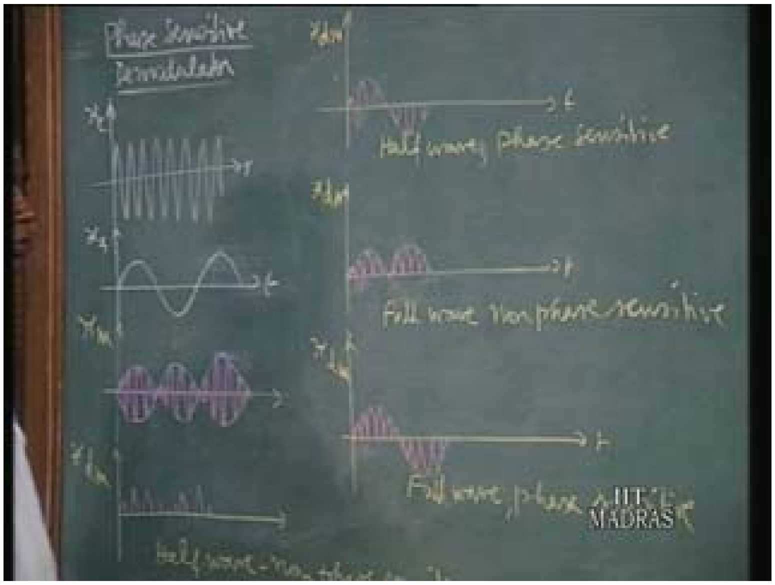

That may create some voltage there and power line we know it is of the order of 50 hertz. So when that noise comes to the amplifier, amplifier cut off frequencies is of the order of 100 hertz so any noise entering into the wire also can be filtered. This is additional advantage of using carrier frequency amplifier. There is no error signal or the disturbance can enter through the wire carrying signal from transducer to the amplifier. That can be filtered by the AC amplifier because of the high frequency cut off of the AC amplifier. As a part of the carrier frequency amplifier, we have phase sensitive demodulator and what is the function of phase and its demodulator how it is achieved we are just seeing here.

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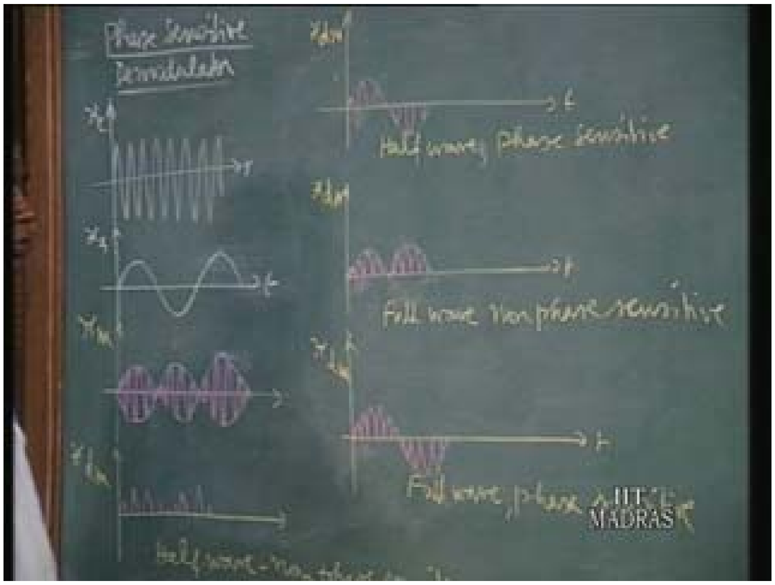

Suppose this is the carrier signal which is coming from the oscillator and this is our desired signal and the X_m that is modulated signal superimposition of these two things and both sides that is our modulated signal, now that is modulation is over. Now demodulation can take place in any one of the four ways. First one is half wave non-phase sensitive, half wave means only from the x axis all the signal available on the positive side alone is left. That is if you take one full wave up to here, this is up to one full wave from this point this point, in this one wave only one cycle only half the cycle alone is there. That's why it is half wave the other half is left so in each cycle only one half will be existing that is only top side. That is a non-phase sensitive means it will not find out plus and minus of the desired signal, signal will be only on the positive side that is a half wave non-phase sensitive demodulator Xd_m demodulator.

Another one is this also is half wave but it is phase sensitive that means the half wave will exist where the signal exist. So first half is positive so positive of the wave, the other half has been lost so one half remains here. Similarly in the negative side, negative signal alone exists on the positive side disappears but you find in each full cycle only half the cycle is there. So hence it is half wave but phase sensitive according to the polarity of the signal, here also signal will exist but now we see the full wave, no wave is lost. Previously it was here it is brought to the positive side that is for non-phase sensitive means only positive side, the last one is brought to the positive side by suitable diode circuits.

So no full cycle is lost, it is brought this side but problem here is non-phase sensitive only positive side. This also is of not much use. So what we have in such carrier frequency amplifier is full wave phase sensitive. That means the other half also brought this side and to the side where the signal exist, so you find without losing the strength of the signal, all the signal is brought to the same side where the signal exist. So you find full wave phase sensitive.

So this is the modulator that’s why we are writing it there, phase sensitive demodulator. It is always meant full wave no part of the wave is lost. Now you find after the low pass filter this will have sufficient strength because no signal was lost, so it has sufficient strength. If it is only half wave, after low pass filter we find it will have only of this shape, only very little strength because I mean half of them are gap but here you find that gap is small so strength will be more. Their voltage level will be at higher level voltage will be there. That is advantage of full wave phase sensitive demodulator. Such a modulator is always used in the carrier frequency amplifier. So that is next one is low pass filter.

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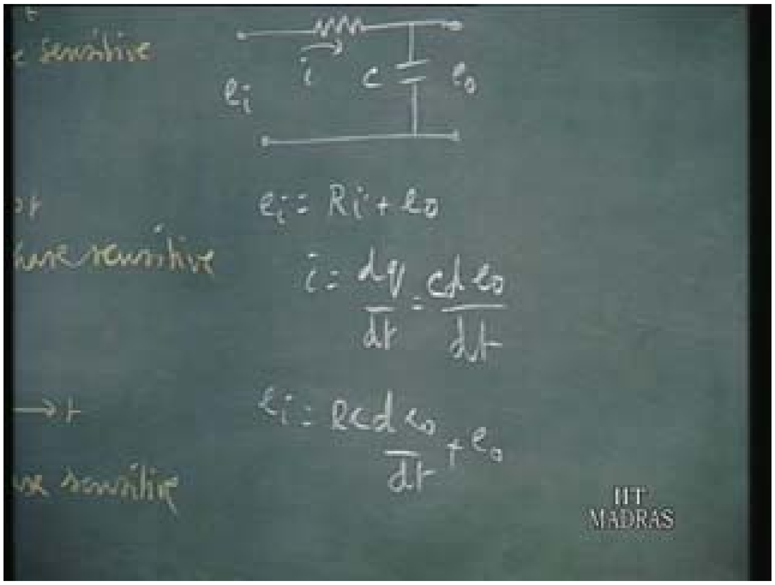

Low pass filter is often used in mechanical measurements, since the mechanical signal is of the order of a say few hertz 4, 5 or 10 maximum may be 10 hertz. So when we want desired signal which is of the low frequency, we go for low pass filter which will allow only low frequency signal, high frequency content gets filtered away. A typical low pass filter is an R C circuit resistance, capacitance. So this will be the e_i and this will be e_o, R and C are the resistance and capacitance. You find this will contain both high frequency and low frequency signal but when it comes out the high frequency content it gets short circuited, capacitor it can pass through it so short circuited; only low frequency component comes here that is physical explanation how this circuit functions.

In case you want high pass filter interchange this place. Put the capacitor here, put the resistance here then you will find only high frequency signal can go through the capacitor and low frequency signal gets cut off that is opposite of the low pass filter, high pass filter. If you apply the Kirchoff’s law we find e_i is equal to R_i, if i is the current flow through the circuit i, R_i plus this voltage drop across capacitor is taken as output voltage so e_o. We know i is equal to current flow through the capacitor i is equal to dq by dt and that is equal to de_o c because q is equal to c into e_o it’s a de_o by dt. Now substituting here you find e_i is equal to R C de_o by dt plus e_o.

Now taking out e_o outside, e_o into R C we can put it as time constants e_o one plus tau D where D is the, this is our capital D differential operator capital D.

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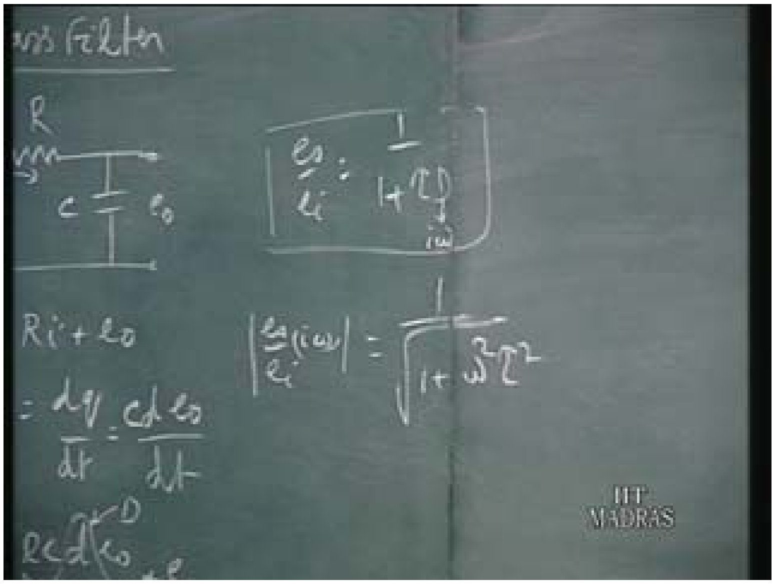

So you find e_o by e_i in other words e_o by e_i equal to 1 over 1 + tau D. So this is a typical equation we have seen for a first order system. To find the magnitude ratio for a sinusoidal input signal e_o by e_i i omega magnitude is equal to substitute D by i omega is a complex number, so you will find root of one plus omega square tau square. So this is the magnitude ratio of the input to output. So you find a low pass filter functions as a first order system with a magnitude ratio of one over root of 1 + omega square tau square. Now what are the functions to be achieved by the low pass filter in the carrier frequency amplifier? One it should pass the low frequency content.

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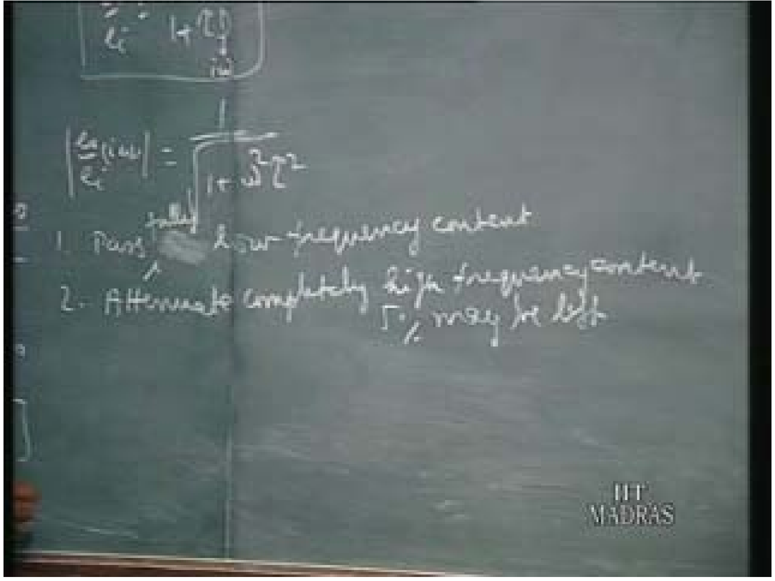

It should pass fully, we will say pass fully low frequency content, the second function is attenuate completely for example completely high frequency content. So these are the desired functions to be achieved by the low pass filter. It should pass low frequency content fully but attenuate completely the high frequency content but this ideal functions but it is not possible. So we find finally the high frequency content may be left, 5% may be left because to realize a time constant to attenuate completely it's not possible. So we allow very little portion of the high frequency content. Actually this is going to our e_i containing low frequency and high frequency content so the high frequencies around 5% rippled that's called 5% ripple is allowed in the output of the low pass filter but it should sufficiently pass the low frequency content without much attenuation this is what is to be done.

So when we design R and C we have to select suitable time constant tau so that these two functions are achieved. For example we have the f_c so the excitation f_c is equal to 5 kilo hertz that carrier frequency and f_s signal frequency is 0 to 10 hertz. In that case we know the modulator to a modulated frequency varies 4890 and 5010 but you will find the demodulate signal will be twice this frequency, it is twice the f_m that is our fd_m. That is frequency of the modulated signal multiplied by two will be the demodulate signal because we will find here twice the frequency of this. That is approximately demodulate signal will be having twice the modulated frequency.

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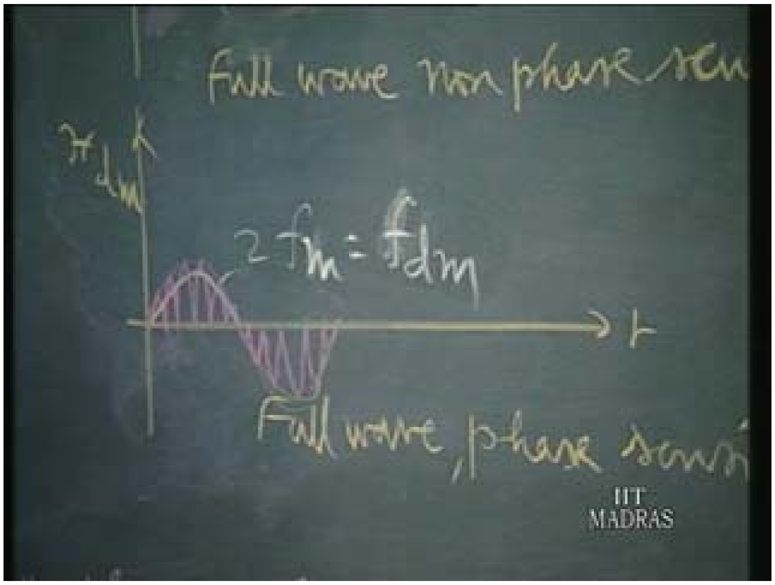

So that is the frequency of the high frequency content, high frequency content will be having a twice the modulated frequency and low frequency will be same as the signal frequency. Now here suppose frequency is 0 to 10 hertz and then in this case fd_m will be so twice 5010 and 4990.

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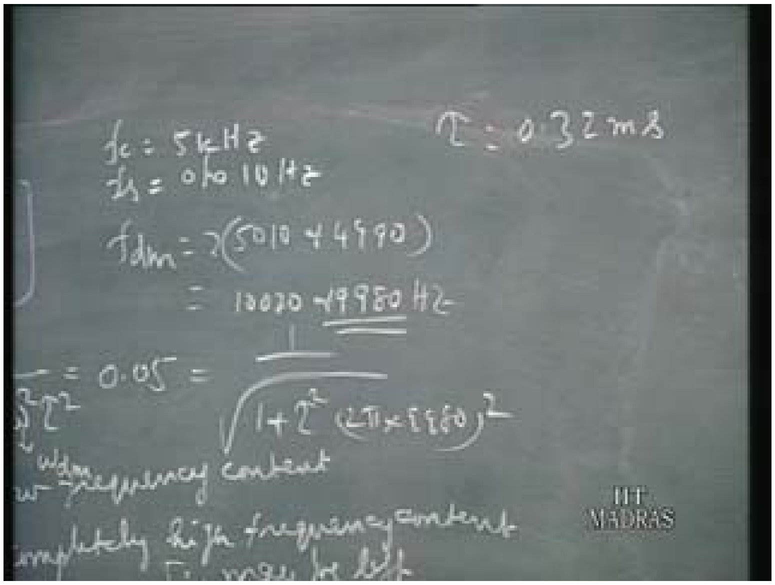

So twice so this is the case, so 10020 and 9980 this is the fd_m. That is demodulate signal will be having this much frequency that is high frequency content will be having a high of this frequency and signal will be having up to 10 hertz. Now if for this one, if we can allow 5% ripple what should be the time constant? So for this 5% ripple we are allowing so that is magnitude ratio is 0.05 when omega is $omega_{dm}$, so let it be lower value so that the whole thing will be maximum. So you have got the lower one so the ratio becomes maximum, maximum value should not be more than this.

So substitute this term here, this is equal to 1 over root of 1 + tau square into omega square is 2 pi into 9980 whole squared, that is equal to 0.05. So here from this we can find out tau, it has been calculated tau is equal to 0.32 millisecond. That is what is at the time constant for a 5% ripple, only 5% of the high frequency content will be there but now you have to check whether this time constants allows the 10 hertz low frequency signal as it is without much attenuation. So we find out what is this x, that is our x_o by x_i or e_o by e_i for the desired signal, i omega for the desired signal this is for signal is equal to 1 over root of 1 plus, now tau squared is 0.32 millisecond 10 to the power of minus 3 whole squared into omega, omega is now 10 hertz. 10 hertz that is 2 pi into 10 square.

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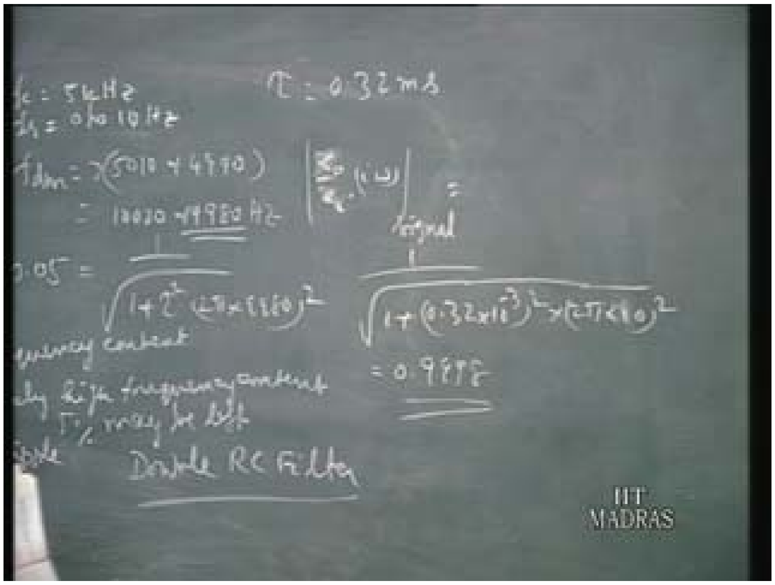

So that is the magnitude ratio for the signal and that comes about 0.9998. So it's near about one so this filter passes the low frequency signal as it is but there are instances. There may be instances you find for 5% ripple this time constant allows only one-third or half the low frequency signal. In such a cases we go for the double RC filter that you will solve the problem in case this is not satisfied.

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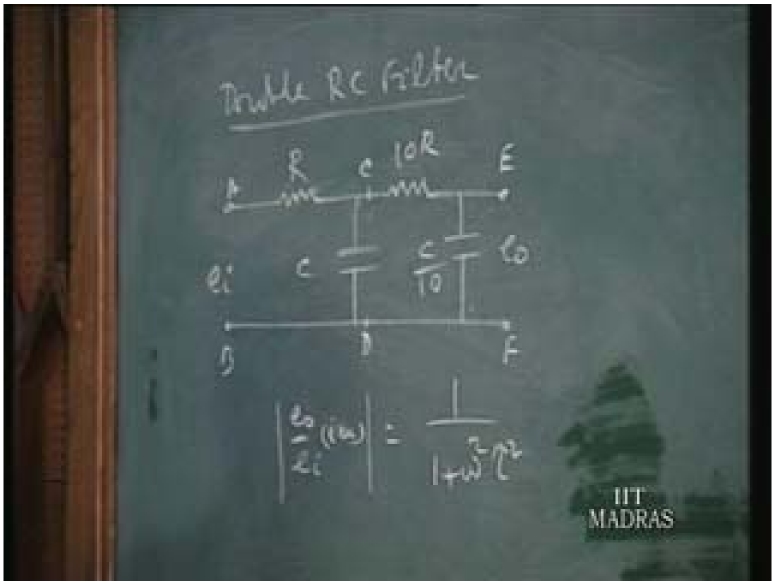

Here now the double RC filter we adopt when we are not getting the desired passage of the low frequency signal.

When it is too much attenuated for 5% ripple then that problem is solved by using a double RC filter, construction is this one. This is up to say point this will be called point A B and this is C D and this is E F. So between A B and C D we have got one RC filter between C D and the E F we have got another RC filter. This is an input circuit to the existing circuit that we know to avoid loading effect the impedance of inputs circuit should be 10 times, that's why you find here R here 10 times R, here C by 10 that's impedance of this will be reciprocal of this. So you got C by 10 will have the 10 times impedance than the C value. So both the R and CR the impedance due to C has magnified, so we find this circuit it's not loading the existing circuit.

So this is a typical double RC filter and we find time constant of this earlier circuit is RC. Here also 10 R into C by time giving raise to again RC that means time constant are both circuits are same as tau. That's you find e_o by e_i for the full circuit so one over for this circuit one over root of omega square tau square and from it here two here again one over root of one plus omega so tau square so both multiply you have got root disappears here. So the magnitude ratio for the full double RC filter is this one. So in this case you take an example that is f_c again 5000 hertz, 5 kilo hertz what we are using and suppose signal is varying 0 to 500 hertz. If this is the case how the single RC filter? Now you will take single RC filter what it does for this signal, for this pair what it does we can work out in the same as you have done earlier.

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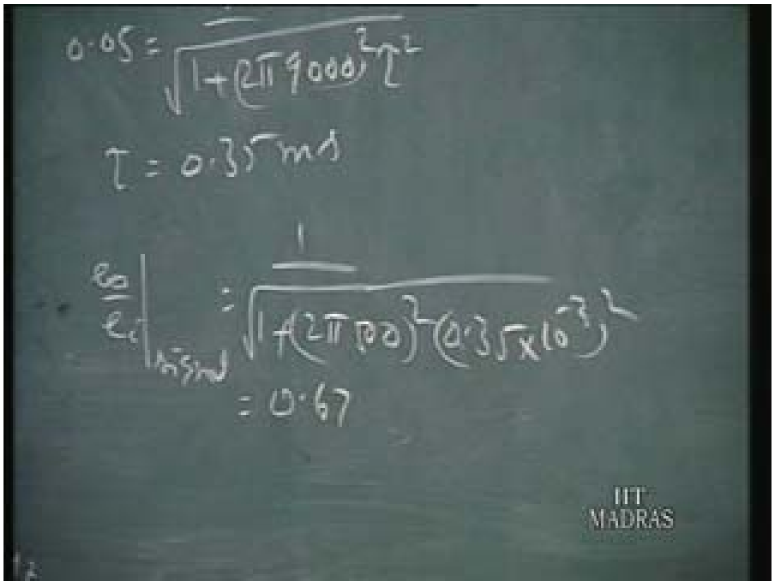

$$0.05 = \frac{\;}{\sqrt{1+(2\pi\, 9000)^2\tau^2}}$$

$$\tau = 0.35 \text{ ms}$$

$$\left.\frac{e_o}{e_i}\right|_{\text{[illegible]}} = \frac{1}{\sqrt{1+(2\pi\, 500)^2(0.35\times10^{-3})^2}}$$

$$= 0.67$$

Now you find the f_m will be 4500 to 5500, so fd_m is double this so 9000 to 11000 hertz. So we take the smaller value so if you work out 0.05 that is ripples allowed one over one plus omega square 2 pi 9000 square into tau square, now that is single RC filter. So tau you get from here as 0.35 millisecond. That is 9000 hertz ripple allowed. For this ripple for this time constant of 5% ripple what happens to the low frequency signal, 500 hertz what will happen?

That is e_o by e_i of the desired hertz signal for the signal is equal to one over one plus this is root of this. This is single RC filter so root of this, root of one plus omega square, omega is 2 pi this 500. 500 is the signal so 500 two pi into 500 whole square into tau square 0.35 into 10 to the power of minus 3 square. So this you have got only as 0.67, so now we find 500 hertz signal is attenuated to two-third of its value, 0.67 will be two-third of it's value one-third of value is lost. So this is not satisfactory so when the input signal is of higher value then the attenuation taking place for desired signal is large. So in such situations we go for the double RC filter now we apply for the double RC filter.

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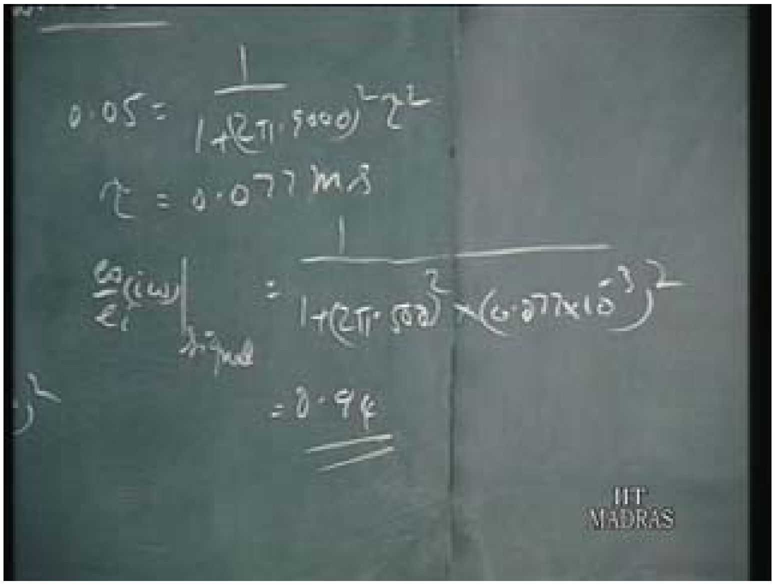

$$0.05 = \frac{1}{1+(2\pi \cdot 9000)^2 \tau^2}$$

$$\tau = 0.077 \text{ ms}$$

$$\left.\frac{e_o}{e_i}(i\omega)\right|_{\text{signal}} = \frac{1}{1+(2\pi \cdot 500)^2 \times (0.077\times 10^{-3})^2}$$

$$= 0.94$$

Now give this signals that is demodulated signal instead of to the signal RC filter, give it to double RC filter this will be e_i from the demodulator it is connected here, having this frequency 9000 to 11000 hertz. Now in this case again for the 5% ripple, you have got one over one plus omega square is 2 pi into 9000 square into tau square. Here tau is equal to 0.077 millisecond though that is millisecond and for this time constant the e_o by e_i i omega of the signal will be 1 over 1 + 2 pi. That is now 2 pi into 500 square into tau square 0.077 into 10 to the power of minus 3 that is millisecond, so minus 3 square now this you have got as 9.4. So now this is acceptable, since the low frequency signal has got 94% of the low frequency signal comes out from the double RC filter.

If the same signal when it is given to the single RC filter up to CD alone if it is single RC filter we get only two-third of the magnitude. So that is how we solved the problem of single RC filter with a double RC filter. So these are the design aspects for a low pass filter. Now we have seen for a low pass filter, how to arrive at time constant but what you have seen earlier to satisfy the two conditions. That it should pass the low frequency signal and cut of the high frequency signal so that a maximum ripple of 5% of the amplitude of the high frequency signal may be left out in the signal output of the low pass filter. So we have seen how to arrive at that particular time constant.

If the time constant doesn’t satisfy low frequency signal then we go for double RC filter. So suppose you arrived at time constant of for a single RC filter, time constant of 0.32 millisecond which you have worked out last time then you have to correspond select R and C to arrive at this time constant. For that we say suppose the instrument voltage measure instrument or with a voltmeter you are going to read the voltage output of the filter. Suppose that voltmeter has got 10 to the power of 4 ohm then this filter circuit comes earlier than the voltmeter, voltmeter is last unit so it should have 10 times smaller one so that this will be 10 times of this output voltage. So naturally in an output resistance so R should be 10 to the power of 3 ohm, so that incoming instrument has a maximum of 10 times the resistance so it becomes ten to the power of four. So once we fix the R of the filter circuit as 10 to the power of 3 ohms then we know tau is equal to RC.

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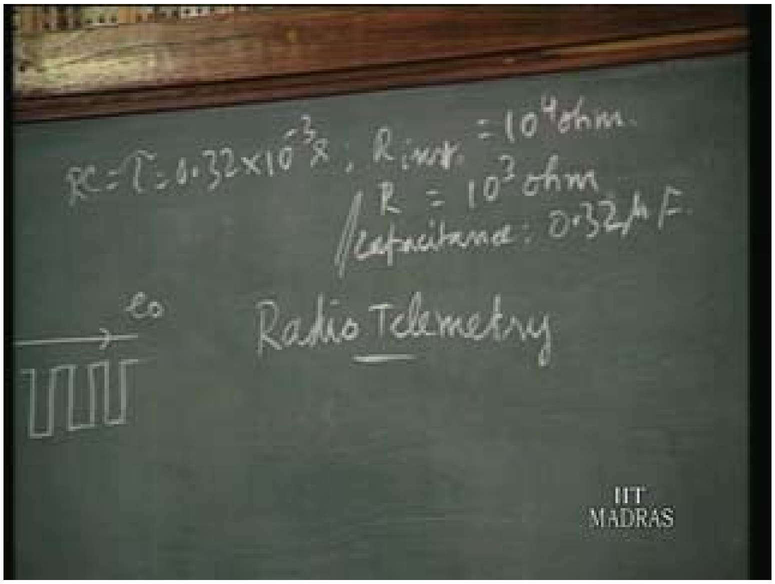

So R is already 10 to the power of 3 ohm so the capacitance will be equal to 0.32, this resistance comes here, again divide by 10 to the power of 3. So it becomes capacitance equal to 10 to the power of 0.32 microfarad. So now with this two resistance capacitance, we have got the required time constant that is how we design the filter circuit. Now we go to the next topic that is radio telemetry, when we have to adopt this radio telemetry that has to be seen first.

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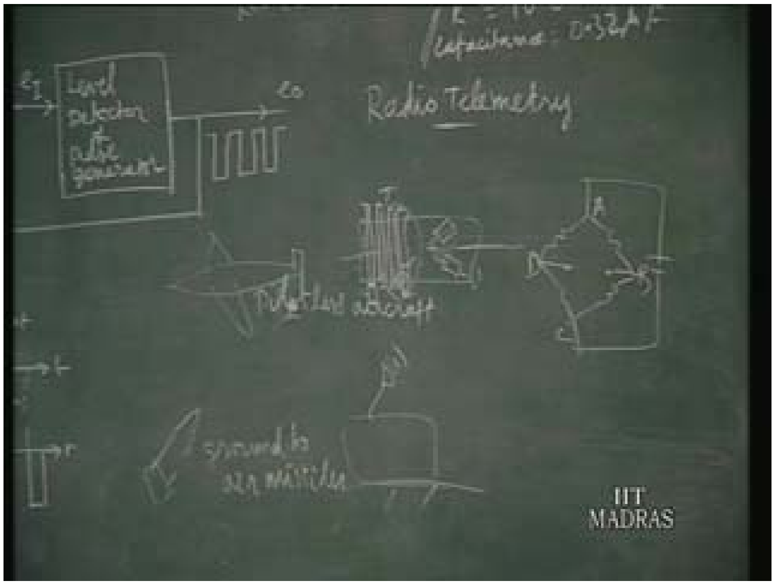

Now there are certain instances where the full instrumentation cannot be located at one place. For example in rotating shaft some torque is there, torque is transmitted by the shaft and we want to measure the torque, it is a rotating shaft. So we fix the strain gauges at 45 degrees which you learn later, so you have got terminals another two strain gauges behind. So four strain gauges built in a bridge circuit and you will have four terminals, for a bridge network we have got four corners we have seen for the bridge network we have got four corners two for the supply and two for the, these are the two say A and C for the supply B and D for the output. So these four terminals are to be connected to the further instrumentations.

So this B and D may be connected to an amplifier and A and B, A and C to be connected to the power supply. So four corners we have, four terminals and you have to connect the four terminals but the shaft is rotating. So what is solution one solution is radio telemetry, you will have your transmitter which will connect this four terminals to a standby instrumentations say power supply and signal processors output unit, all at the ground floor and this is rotating system. So to connect these two things we will have the one antenna here which will transmit the signal for all the four terminals and similarly here also you will have an antenna which will carry this signal with the four terminals signal or voltage supply whatever it is, will be carrying into there. So this is the radio telemetry.

The separated instrumentations systems are connected together by radio telemetry without any physical contact. This is one instances where radio telemetry is made use of. Second instance is suppose you have got an aeroplane and is suppose it is enemy aeroplane and we have got our missiles. Suppose this missile is to hit it and for that we have to develop the technology. So in its defense laboratories now they select so called ground to air missiles. To find the efficacy of this ground to air missiles you should have an aircraft so that when it flies in zigzag position how this missile hits the aircraft?

For conducting this test you have to use a so called pilotless aircraft. So we don't have any pilot there and this aircraft should take all zig zag path. How to control this flight? That is possible only by having radio telemetry. You have the power supply or signals at the ground and give for the radar where to turn and all we give the signal and their signal is picked up and there you have got power amplifier, everything there and it rotates the elements of the radar or some of the elements of the aircraft and it takes different direction. In fact the aircraft will take different directions and thereby making it to fly a different directions then you fire this whether it hits it. So all necessary controls to the aircraft as well as the position of this aircraft will also be picked up by the ground instrumentations or telemetry systems.

So the instrumentation from ground to the pilotless aircraft is achieved by having the radio telemetry. So these are the uses of the radio telemetry to wherever you connect it, you can go for radio elementary. What is alternative? You can have four slip rings, four terminals for these four slip rings we can have. This is cheaper but the problem is we may have some error due to the brush contact may be varying as per the usage and later on you may have noise signal due to this varied contact resistance between the brush and the slip rings. So this is avoided by having radio telemetry. The disadvantage of a radio telemetry is its very costly whereas slip rings are very cheap so still people go for slip rings but this may cost few hundreds whereas radio telemetry may cost around few lakh, so this is the main difference.

Now having learnt about this usage of this radio telemetry, now going to the principle of operations now we have got different constructions for radio telemetry. One of the construction is say 16 channels radio telemetry system and that is what the block diagram is shown here, block diagram of a radio telemetry systems.

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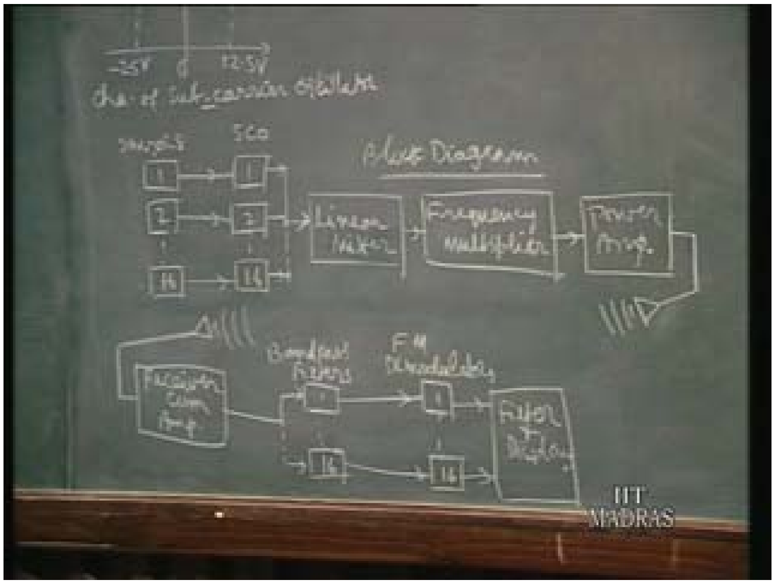

Now you have got 16 channels and 16 channels means for 16 sensors. So here you have got 4 corners so 4 channels are sufficient for a bridge network but what is available in the market is 16 or 32 like that. So for example if there are 16 channels we can also have 16 sensors or instruments, transducers and for each transducers output may be varying between minus 2.5 volt plus 2.5 volt, proportional to this voltage output of the transducer you have got the voltage output from the so called subcarrier oscillator. It is called subcarrier oscillator changes the voltage to frequency. If the voltage is zero we have got center frequency say it may about 100 hertz for example and if it is 2.5 volt you have got 107.5 frequency and here you will have 92.5 is a minus two point. So 92.5 to 107.5 hertz it will varying according to the voltage.

So it converts that voltage to subcarrier oscillator, voltage to frequency converter that principles is explained there, I will come little later. So you find once voltage is converted into frequency, all of them are mixed together simultaneously. So it can be transmitted at the same time now it is done frequency multiplier. It is probably the smaller frequency range is multiplied in terms of megahertz. So say 20 megahertz like that is for 10, 20, 30 mega in terms of megahertz it is multiplied so by 100 or 10 to the power of 4 times it is multiplied and you will have the frequency in this range and now we have got a power amplifier to cover a distance, higher the distance higher power is required then it goes to antenna.

Now the antenna size is same as the wave length of this propagation frequency, so in order to have a smaller wavelength we increase the frequency because speed of the propagation is same as light. So higher frequency means smaller wavelength then antenna waves also will be of the same order of the wavelength. So it is received here and then we go the negative I mean reverse way. Here signal loss converting into frequency now the frequency whatever is available here, go through different for example full band pass filter one we have got tuning we can select the signal corresponding to sensor one. So for sensor one it may be varying 92.5 hertz to 107.5 hertz.

So you will have a center frequency around 100 hertz so around this band it will allow then demodulate and the same voltage will come here and it goes through filter and display and you can get the same variation of the signal variation here. So that is how the instrumentation is connected by this radio telemetry systems. Now how this voltage is converted into a frequency? Now we see this diagram, here this is the voltage to frequency converter.

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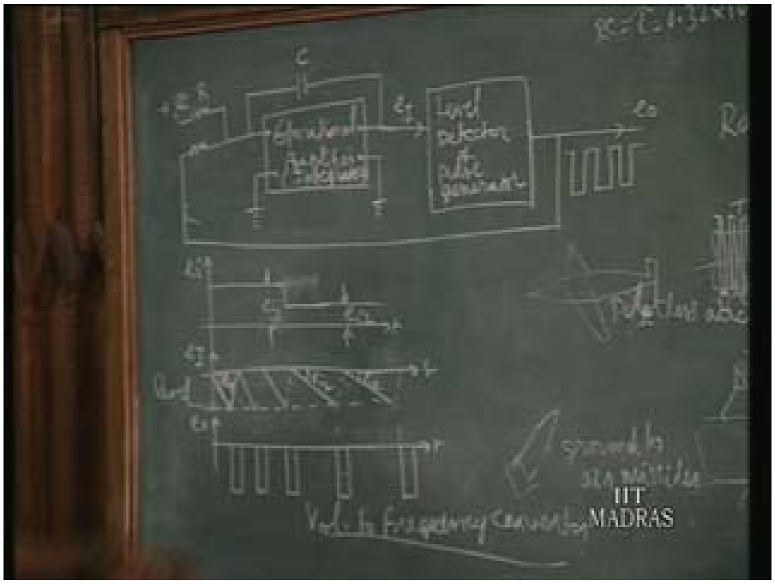

Now this is our voltage e_i which is varying minus 2.5 volt to plus 2.5 volt and this operation amplifier with a feedback capacitor it functions as an integrator. Now the integrated value that is suppose e_i is varying like this, suppose e_i is constantly e_{i1} then we find e_{i1} is the input so operational amplifier integrator has got an input and the voltage output e capital I will be increasing as per the voltage e_{I1} value. So when it reaches the level this is level, it may be minus 5 volt or so whatever it is we can select, level detector come pulse generator. Level can be detector can be set an n value. When the integrated voltage reaches this then one pulse generated by the pulse generator, when e_i is increased to pi the level detector detects that and then one pulse is made one negative pulse so though it may be minus 10 volts or something like that. So one pulse is made.

When pulse is made the pulse is fed back and then we will find plus and minus, this minus value it becomes zero then you will find this becomes the integrated value becomes zero. When it becomes zero again e_i is always there, so e_i again the e capital I will be increased. So that is how pulses are made at particular frequency. That is proportional to e_{i1}. Suppose e_{i2} is smaller than e_{i1} as per this diagram. Now e_{i2} will be a smaller value so the rate at which the voltage increases, integrator voltage increases will be smaller, so to reach minus 5 volt for example it will take more time. So from here to here you have got a longer gap and then one pulse is made and a negative pulse is fed back and it goes to zero and the e_{i1}, e_{i2} is there so it again increases so this is again same value e_{i2}.

So you find for a smaller value of e_{i2} you find the frequency has reduced. So you find the frequency of the output is proportional to the voltage here. That is how the subcarrier oscillator, this is subcarrier oscillator converts the voltage developed by the sensor into a corresponding frequency and then this frequency is multiplied some here and there it is linear mixing all together so that it can be transmitted.

So that is how the radio telemetry functions. With this we complete the so called the fundamentals of measurement. That is our fundamentals of measurements.

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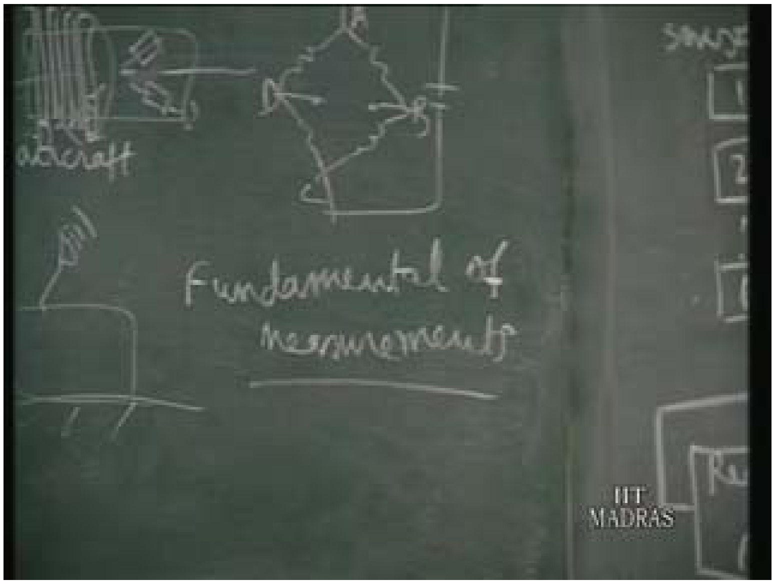

Later we will see that is we may call as second part. Up to this we may call as part one, in second part we will have the specific measurements like displacement, velocity, acceleration, force, torque, temperature, flow, pressure and so on. So that will be second part.