# Electronic Systems for Cancer Diagnosis

**Dr. Hardik J. Pandya**
**Department of Electronic System Engineering**
**Indian Institute of Science, Bangalore**

## Lecture – 35
## Basic building blocks of Electronics System: Data converters (contd.)

Hi welcome to this module. And in the previous module what we have seen? In the group of modules we have seen how different amplifiers we can generate using the operational amplifier like what are the applications such as, not inverting amplifier, inverting amplifier, unity follower, summing amplifier, differential amplifier. We have also seen a few filters; where we are talking about low pass, high pass, band pass, band reject righ? Then we have focused on the data converters which are analog to digital data converters.

Now, let us see here what are the digital to analog data converters and then we will take few examples of how we can design a complete signal conditioning circuit so that you can interface it with sensors or transducers. All right,

So, when I talk about signal conditioning circuits, in the first block is always how to convert the signal to a different domain. And that is there for example, if I have a sensor which is showing the change in form of resistance, how can I change that form of resistance and as a final form a is some kind of display. Then that resistor has to change it to voltage, that voltage has to be signal conditioning, we have to use it so that we can amplify the voltage, filter out the noise and then convert it to a digital domain so as to run the microcontroller and finally, you need to display it on some kind of display module.

It can be LCD LED or whatever the display model may be. And what is the importance of instrument amplifier? Whatever the things that we have been learning in the earlier modules we will be used utilizing all those things together combining it and then it will make the entire electronic system.

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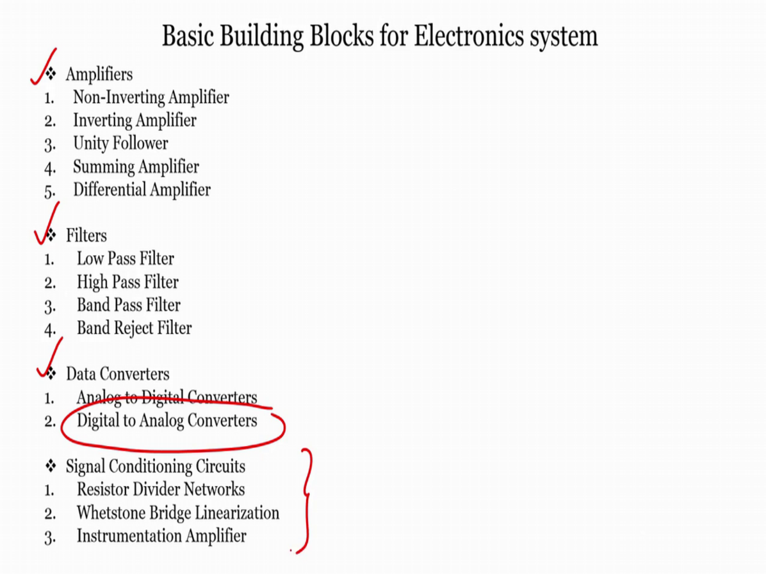


So, if you see the screen what you can see that we have seen the amplifiers right? Filters, data converters. Let us see for today, digital to data converter and then we will follow about the difference in their conditioning circuits.

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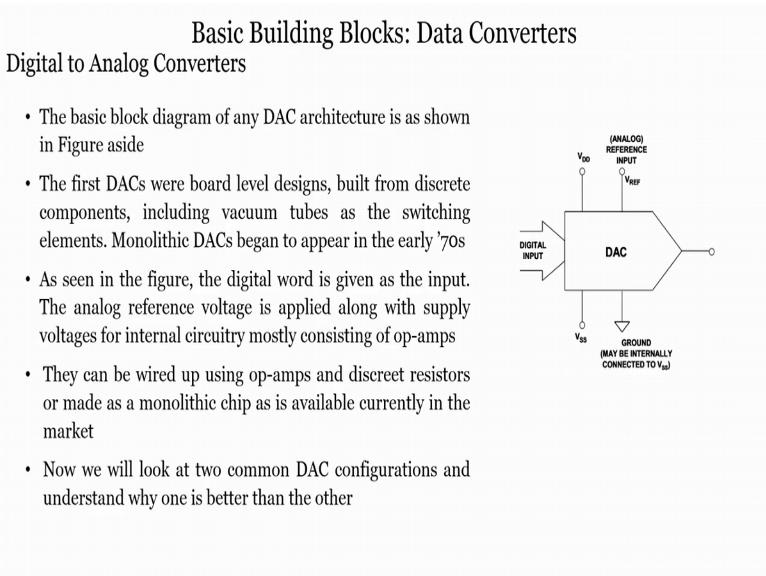


So, if you see the data converters, then the basic building block of DAC looks like this. Where you have the digital input, right? You have a reference analog voltage and then you have ground and then V s s and V d d which is the supply voltage and then the output would be a analog in the analog domain.

So, the basic building block of any DAC architecture, you can use this block to show a block diagram. The first DACs were board level designs field, built from district components including vacuum tubes as the switching condiments. The more of the ting DACs began to appear in early 70's as in the figure the digital word which is here is given to the input, analog reference voltage is applied with supply voltages for internal circuitry mostly consisting of operation amplifiers. The it can be wired using op-amps and discreet resistors or made as a monolithic chip as is available currently in the market.

And finally, we will we will look at two common DAC configuration understand why one is better than the other one.

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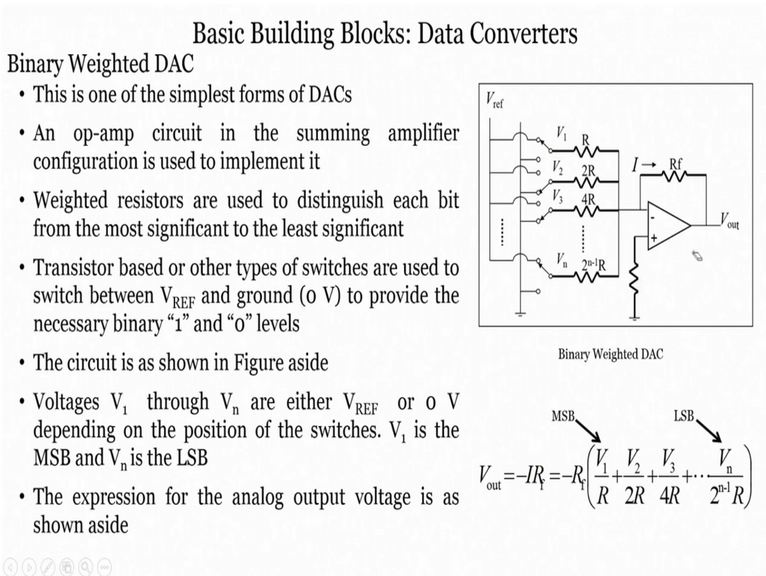


So, if you see the DACs, there are 2 types of DACs. The first type that we are discussing right now is the binary weighted DACs. now this is one of the simplest form of digital to analog converter and operational amplifier which you can see right over here. Right? in the summing configuration, if you see the summing amplifier what was summing amplifier? That all these voltages were summed together and amplified at the output. So, this is similar to a summing amplifier, so this is used to implement the DAC as well.

And weighted resistors that are you see here the resistors values are seen from R, 2 R, 4 R, 2 raise to n minus R from V 1 to V n. If you have different voltages from V 1 to V n, the weight of the resistors would change and that there is a reference voltage. If reference voltage is exceeding the value of the voltage, then it will there will be change in the output. We will see how this works. Just let us first understand the circuit in detail.

Now, weighted resistors are used to distinguish each bit from the most significant bit to the least significant bit. You always write most significant bit as MSB where LSB is the least significant bit. Transistor based or other types of switches are used to switch between the V reference and ground. Now you see here there is a ground and here there is a V reference. Depending on 1 or 0, you have to change the voltage. We will look at it later so that we can give different binary inputs all right because, binary is given in the either terms of 1 which is high or 0 in terms of the ground.

The circuit is shown here voltage is V 1 through V n and either V reference or voltage. You see if I connect this switch to V reference and them I a voltage would be V reference here right or, if I connect this switch to ground right? Then what will happen? I will have here 0. So, either it is V reference or 0 depending on the position of the switch. V 1 is the most significant bit and 0 and V N which is the nth bit would be the least significant bit ok.

So, the expression of the analog output for the weighted binary digital to analog converter is given by V out equals to minus IR f. What is here I? I minus I would be nothing, but the summation of all this voltages so V 1 by R 1 plus V 2 by 2 R so V 1 by R here V 2 by 2 R, then V 3 by 4 R and so on and the V N by 2 raise to n minus 1 R. So this is the least significant bit this is the most significant bit. So, this is a bit a binary DACs is ok.

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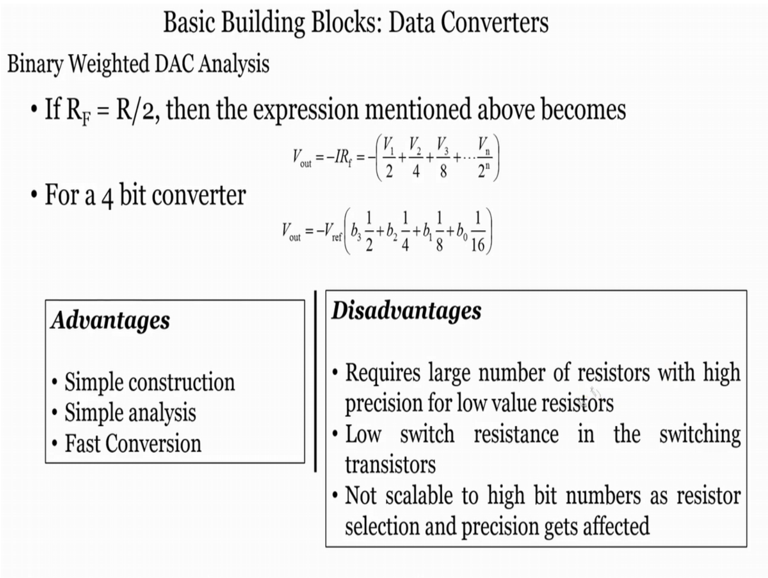


Now, if I go further if my R F is R by 2, then the expression would be V out equals to minus IR f equals to minus V 1 by 2 plus V 2 by 4 plus V 3 by 8 so on and then V N by 2 raise to n. For a b a 4 bit converter it is minus V reference right? V out equals to minus R f so for a four bit converter, we will say it is like V out equals to minus V rf and then we have 4 bits b 3, b 2, b 1 and b 0. So, it will be like 1 by 2, 1 by 4, 1 by 8, and 1 by 16. Right ? So, its. So, easy to convert your digital signal to analog domain by using this particular DAC.

Now what are the advantages and the limitations of this particular DAC that is the weighted binary DAC. The advantages are; that it is extremely simple to construct. the analysis is also simple and the conversion it faster. While some of the limitations are, it requires large number of resistors right with precision for low value resistors; because you go on reducing the value of resistor, as you can see here, right? There is a V 1 by R 2, R 4, R 2 there are very large bit of resistors are required and extremely precise values are also required.

Low switch resistance in the switching transistors is another important in a point. We have to take care of and then finally, this is not scalable to high bit numbers as a resistors election and precision gets affected. So, these are some of the limitations of the digital to analog converter.

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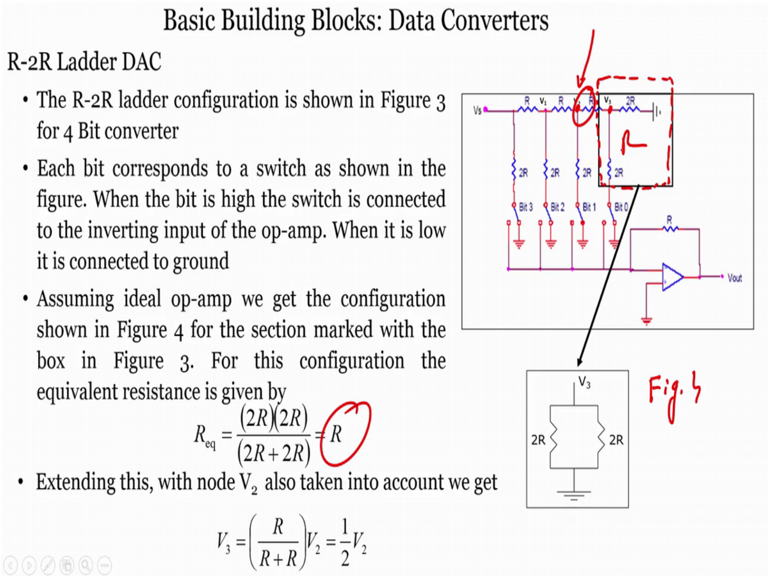


If you move further, then the second kind of DACs is called R-2R ok. So, the R-2R DAC is shown in this particular schematic we can give a number figure 3 its just a figure. Do not worry about it. And its for 4 bit each bit it corresponds to a switch as shown in the figure you can see there are 4 bits, at bit 0, bit 1, bit 2, and b 3, and each bit corresponds to a switch which you can see here.

When the bit is high, then what will happen? The bit is high. the switch is connected to the inverting input. You can see an amplifier and inverting input of the amplifier is connected to the switches and also the ground is connected to switches.

So, either you the switch will be connected to the inverting amplifier or inverting input of the amplifier or it will be connected to the ground rght? So, assuming the ideal op-amp we will get a configuration as shown here. So, let us say this is figure number 3 and this is figure number 4.So, for this configuration the equivalent resistance can be given as. So, if I see now you see this is very very interesting if I take this block ok, if I take this block. Now the configuration is very simple because here is always R-2R you see let us first understand, see this is resistor R there in 2R, R 2R, R 2R, R 2R and 2R, why here last is 2 R? We will see about that.

So, if you see from the last block that is from here. And if I have the equivalent circuit of that 2R, 2R right at these then what will happen? My R equivalent would be 2R multiplied by 2R divided by 2R plus 2R. And if I do that, my answer would be R right?

So, this is nothing, but R resistor R. So, this 2R and 2R will be and resistor R. Extending this node to V 2, also taken into account we can have. So, if I take this V 3 is done, now if I take it to V 2, What will happen for here? It will be R in it will be like this R and R.

So, it will be sorry R divided by R plus R. see if it is just here R and then there is this is equivalent is R. Then what will happen this one is R by R plus R into V2 which is 1 by 2 of V2 its very, its very interesting and very easy also. The same way, you can extend it further to.

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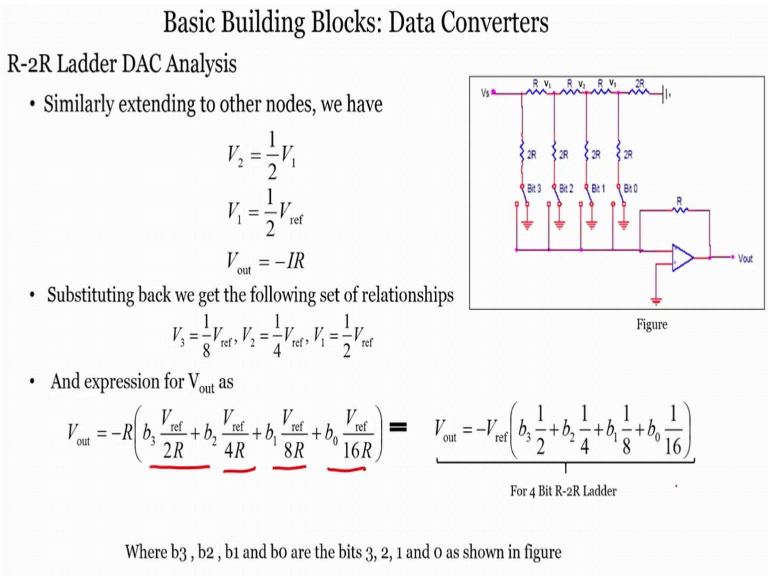


To the further nodes, now if we extend it to other nodes we can see V2 equals to half V1, V1 equals to 1 by 2 of V reference and V out would be minus IR. Now if I substitute this value then we have, V3 equals to V3 equals to 1 by 8 of V reference. V2 equals to 1 by 4 of V reference and V1 equals to 1 by 2 of V reference and the expression for V out can be given as minus R into b3 V reference by 2R b2, V reference by 4R plus B1 V reference by 8 R plus V0 V reference by 16 R. In another way, if I want to further write it down I can write down as V out equals to minus V reference then b3 1 by 2 plus b2 1 by 4 plus b1 1 by 8 plus b0 1 by 16 and so on and so forth.

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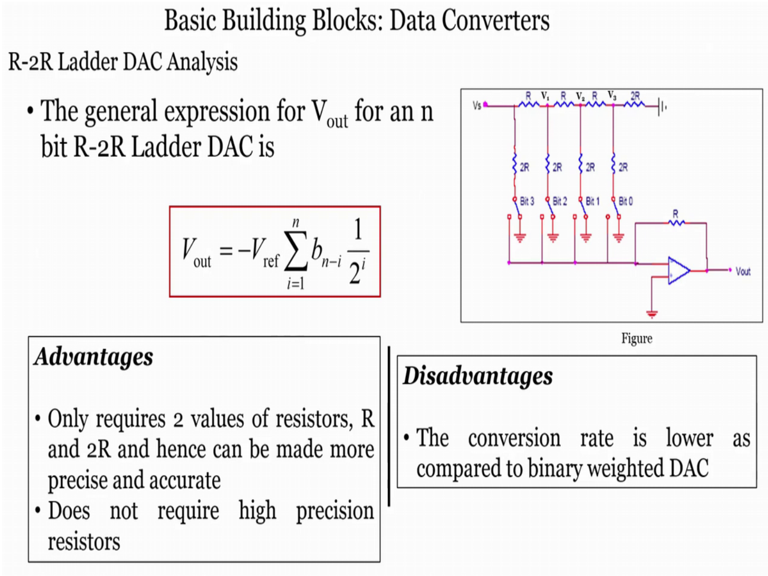


So, for this 4 bit R-2R ladder where we have this b 3, b 2, b 1, and b0 as bits 3, 2, 1 and 0 and if I want to have n number of bits then the general expression for the R-2R ladder would be V out equals to minus V reference summation of I equals from I equal to 1 to n b n minus i into 1 by 2 to the power i. this is the expression for the n number of bits for R-2R ladder and this again the schematic is shown in this particular figure.

The advantages and limitations of the R-2R DACs are the first one is that the it was only 2 values of resistors and in case of the weighted binary network; we require very high value of resistors and extremely precise value of resistors. While if you talk about the DACs using R-2R ladder then the advantage would be that it only requires two values, either R and 2R and hence can be made precise and accurate. Second advantage is that does not require high precision resistors that is a second advantage. This disadvantages of the R-2R ladder is the conversion rate is lower as compared to binary weighted digital to analog converter ok.

So, these are the disadvantages again its a only disadvantage.

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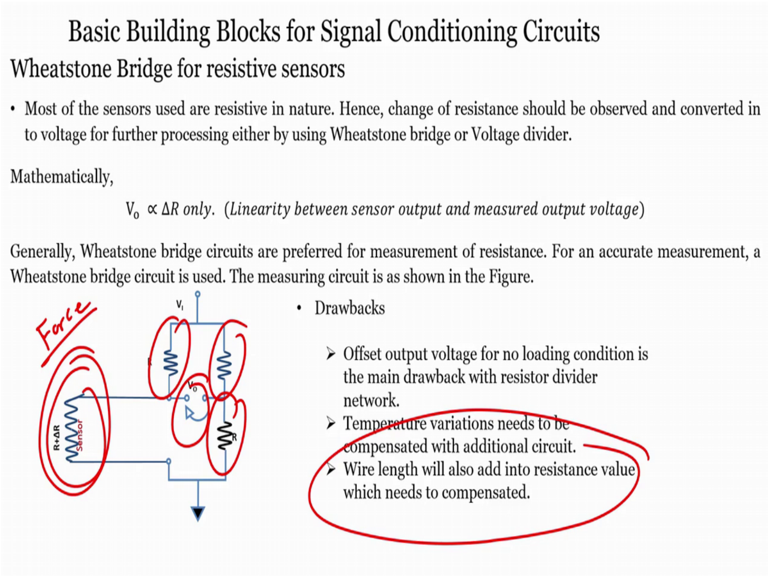


Now, let us go to the next module. And the next module would be a basic building blocks for signal conditioning circuits. So, this is really interesting because how we can use or convert our resistors change in resistance value to different domain that is our voltage domain. So, like I give an example if you have a pressure sensor and if the pressure sensor is made out of a pressure resistive material, when we apply a force to a pressure to the resistor what will happen? It will be the sensor will bend and the corresponding resistance would change corresponding to the applied force or pressure.

So, how can I change this value of resistor to another domain? That is the question and if you see the slide what you find out is the wheatstone bridge for resistive network is one of the answers to our question. That most of the sensors used are a resistive in nature. Hence the change of resistance should be observed and converted to a low voltage for further processing ok. Then the second thing is that, the this can be done further processing can be done by using either voltage divider or wheatstone bridge.

So, how it can be done? Suppose I have a resistor right and I use sensor as another resistor and this resistance which is R sensor so it will be changing this will be constant R and let us say if I apply voltage V. V equals to let us say 5 volts all right? So, if my R equals to R S when there is no and this sensor is let us say force sensors. Force sensors. So, initially what will happen ?

I will have R equals to R S right? R equals to R S. So, here I will have voltage as 2.5 volts right? because its a potential divider network, resistor divided network. The, so the at when there is no force, so force equals to 0, I will have 2.5 volts. When I change my force this resistance value would change and this voltage value would change. But if you see that the amount of voltage that is the total voltage that we apply supply voltage is 5 volts, but our starting voltage here is 2.5 volts.

Thus the range would be from 2.5 volts onwards that is almost half of 5 volts. That is why the this kind of resistive divider network is not used and we go for or we opt for Wheatstone bridge which is shown here and mathematically V o is proportional to delta R only linearity between sensor output and whether the output voltage. Generally, Wheatstone bridge circuit which is right over here you can see here there are 4 resistors and the 4th resistor is your R sensor we cut it like this because your sensor will change the resistance value and that is my R plus delta R.

Generally Wheatstone bridge circuits are preferably for measurement of the resistance, for an accurate measurement of a Wheatstone bridge circuit is used. The measured circuit is shown here and the drawbacks of this are offset voltage offset output voltage for no loading condition is a main drawback right that is the first thing.

Second thing is temperature variation needs to be compensated by additional circuit and finally, the wired length will also add into resistance value which needs to be compensated. So, you see the temperature if the temperature of the resistor changes how it is compensated? That is the drawback and finally, the wire length will also add the resistance values to for the compensation. So, that is another thing that we need to take care yeah.

So, we were looking at the drawbacks and like I said there are few drawbacks particularly output offset voltage for no loading condition; that means, that even when the resistors are all in the initial stage and there is no change in the resistance because let us say again this resistance is our force sensor. So, we are not applying any force then all the resistance values are same still you will find some kind of offset voltage at the output and that offset voltage we need to null it that is one, one drawback. Second thing is that with respect to temperature the things would change and finally, the wire length that we already discussed.

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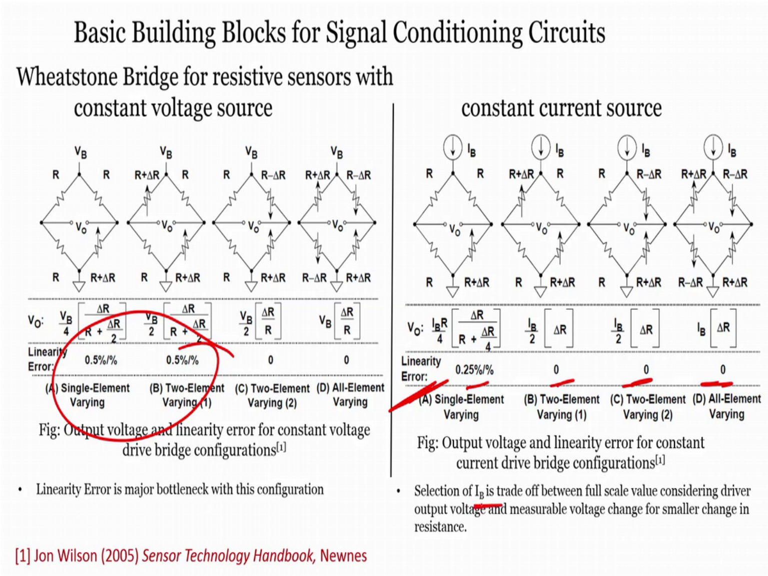


So, if you further go the basic building blocks for signal conditioning circuits when we talk about the constant voltage source, so that it means that Wheatstone bridge for resistive sensors with constant voltage source and constant current source how it will differ and let us look at this. So, if you see a lot of things we have merged in one single slide very informative slide.

So, if you see here we have voltage V out which is here this if you see this particular configuration where only one resistor is changing right? Then we have V B by 4 delta R by R plus delta R by 2 and here the linearity error would be kind of 0.5 percent and then you can also see further that if I have 2 resistors value which are potential dividers sorry which are potentiometers then I will have my output voltage as V B by 2 into delta R by R plus delta R by 2.

Similarly if I use this particular configuration and here when one resistor is changing it is increasing the resistance, the second resistor will be decreasing the resistance. This will be the case of cantilever beam where you have the resistor one in the bottom and one the top is a resistor. When you apply a voltage, the cantilever beam will move will bend and there will be compressive stress and there will be tensile stress and because of which there is be change in resistance one will be increasing, one will be decreasing. The final one is, if you have all 4 resistors in this particular format with the constant voltage source, then we have value V B into delta R by R.

So these are the configuration for single varying element to all element which as in varying nature. So, if the figure shows the output voltage and the energy and for constant voltages, these are all output voltage and linearity error you consider that the error in case of this bridge as well as this bridge is 0 Right?

So, you preferably we should go for a 2 element varying or all element varying bridge configuration. When you talk about constant current sources, then you can see here for the first configuration, we have voltage equal to I B R by 4 into delta R by R plus delta R by 4; where you have the second configuration which is similar to this one right ? We have I B 2 I B by 2 into delta R. now here the output voltage will be different because now we are using a constant current source.

Finally, we have the 2 varying element, we have I B by 2 delta R and finally, we have all varying element then we have I B into delta R right? So, the output voltage and then linearity error for constant drive bridge circuits configurations are shown here. Here the linearity is 0.25 0 0 and 0 right?

So, the here for the constant voltage source we can see that linearity error is major bottleneck with this configuration right? While in the case of a constant current source, what we find is that selection of I B is trade off between full scale sorry between full scale value considering driver output voltage and measurable output change for small change in resistance right.

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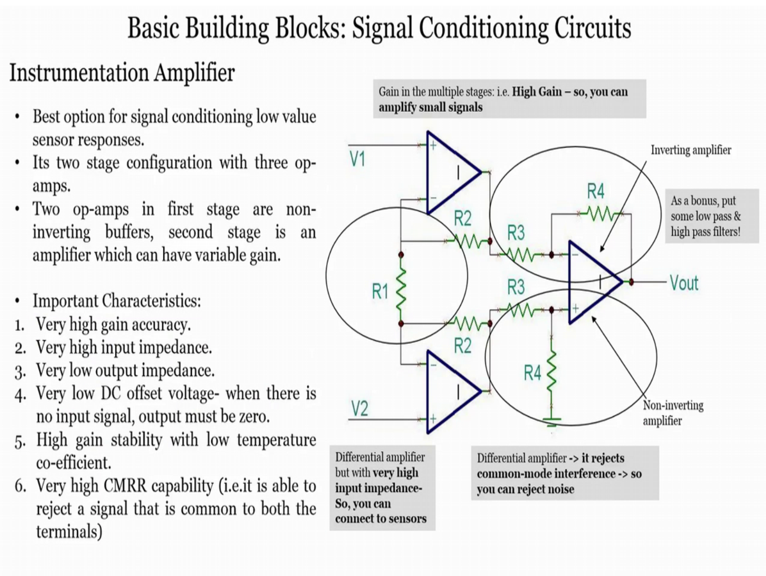

So, there is another thing we need to take care of when we are designing the signal conditioning circuits right? So, let me end my this module here. And I will continue with the further signal signal conditioning circuits in my next module. Till then just go through what we have learned and I will catch you in the next module with more information about how to the instrument amplifier has can be used in the case of the signal conditioning circuits.

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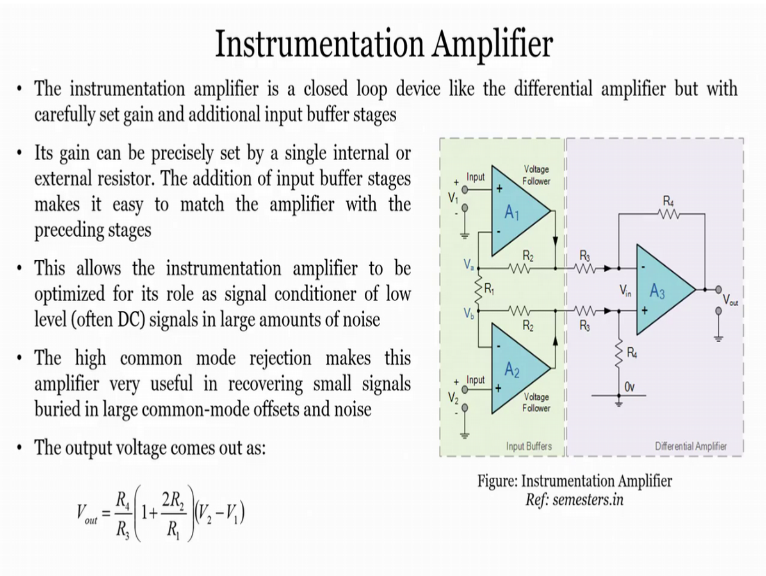


So till then you take care.

I will see in the next module bye.