Lecture - 36
Signal-conditioning Circuit for Hot-Wire Anemometer
Part 2

Hello everyone, welcome to the next module, on industrial applications using op amp.

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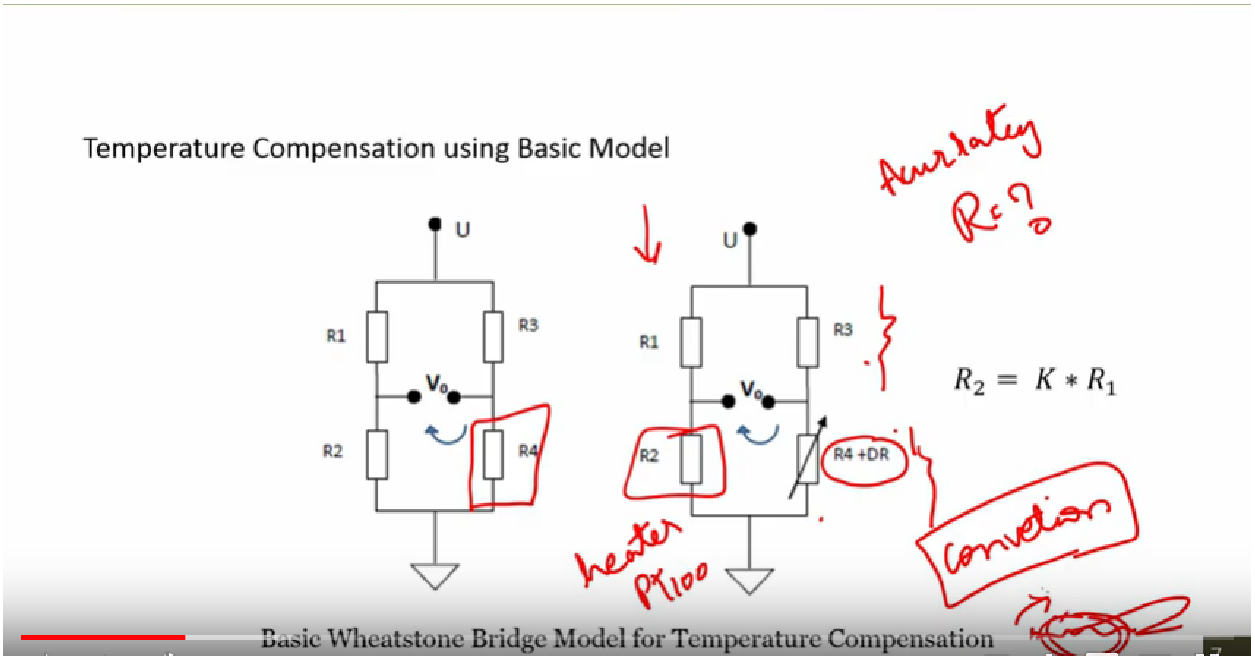

Today, let's study temperature compensation using the basic model, like I already mentioned, where do you place the temperature compensation? And how does it affect the bridge and your resistance, becomes important. Like, another question what I would raise here to you guys is? What happens if I change the copper, so this is the temperature compensation circuit? What if I remove the resistor here and place it here, would the circuit still work, would you be still able to measure accurately, what is the speed or this change in resistance, depending on the rate at which the fluid is flowing. So, this is a brainstorming session, where you have to go ahead and look, what if I remove my temperature compensation from this to this, would your circuit still work, would the feedback be more appropriate, would it be cumulative, so how does it work? So this, I leave it to you and understand, why the temperature compensation has been placed here, if this becomes my heater or in R case is the PT 100. So, another important factor is, what where I always talk about, convection. I hope you know, the term I mean, I hope you understand, what is the meaning of convection? So, it is the rate at which the heat is being transferred to the medium, so the cooling effect, as air flows through the resistor, so there is some sort of a cooling effect which happens and he tends to move in the direction of the fluid. So that cooling effect is called, ‘Convection’.

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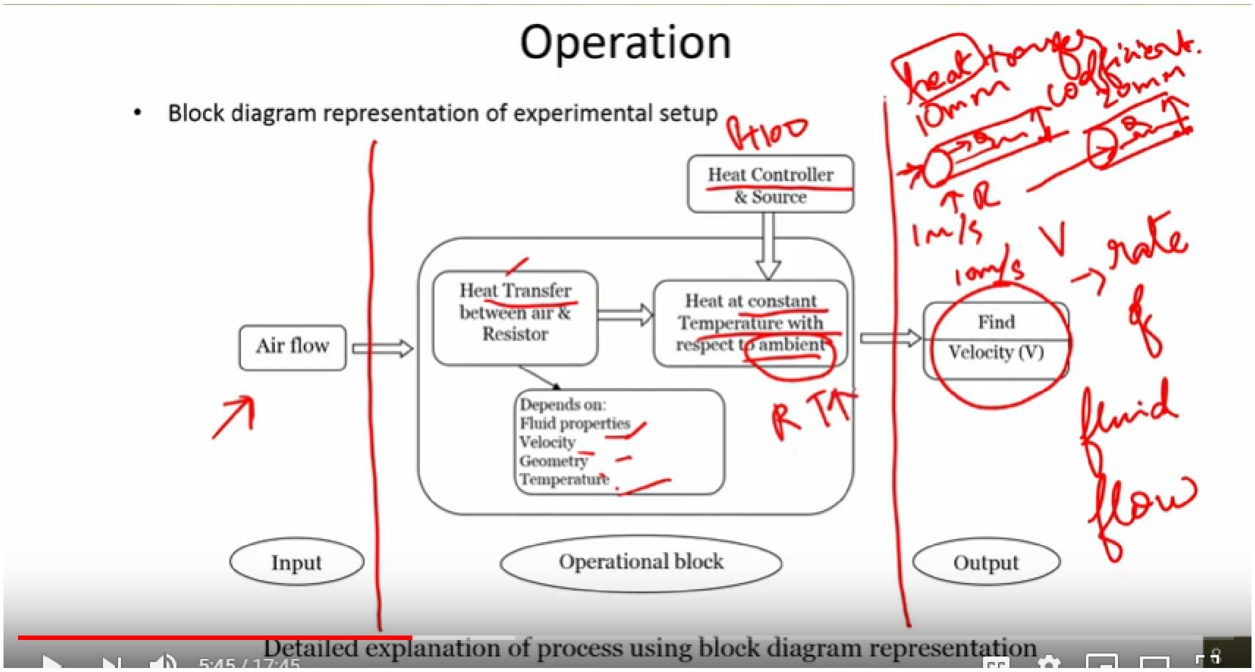

So how do you recover the entire circuit, what are the different blocks? Input in our case is air, like I mentioned this, there's the different applications, the based on the type of fluid, when I say fluid, it could be liquid, it could be gas. All that parameters also becomes important, when you're designing a measuring unit, in order to understand the velocity of the fluid that flows through your chamber. Here, it is air and how the transduction happening, you would get what at, you would find out what is the velocity? So, the input is air, ultimately what you need is, the velocity or the rate at which the fluid is, flowing. And what goes into the operational block. Here, heat controller and source. The heat source here is the PT hundred and then, there is a heat transfer, between air and resistor. And again, the rate of convection depends on, the fluid properties, the rate at which the velocity, fluid flowing, the geometry and temperature.

Say, I'm using a pipe, which is 10 mm dia and then, I have a sensor and then there is airflow. And then you want to measure, the rate at which the fluid is flowing through this, assume I have a 20 mm dia and the fluid flows in this direction and you have the heater, would the rate of convection, be same so, this is just to tell you that geometry, plays a role when you are talking about, the heat transfer rate, which depends upon the type of fluid, some fluids would have very high thermal capacity, the heat transfer coefficient is different for each fluid. So that would be heat transfer coefficient is, specific to each fluid. So, when you make your mathematical model, make sure you, would consider these parameters. The velocity at which the fluid is flowing, it cannot be the same, one meter per second, 10 meter per second, the rate of fluid varies, the amount of convection varies, R various, temperature varies. So, all of this has to be considered, the geometry temperature. And in R case we are talking about, a constant temperature circuit, with respect to the ambient. When I say ambient, always ensure that your compensation circuit; maintains the resistance at ambient temperature, in order to keep your fridge, balanced and to have an accurate measurement.

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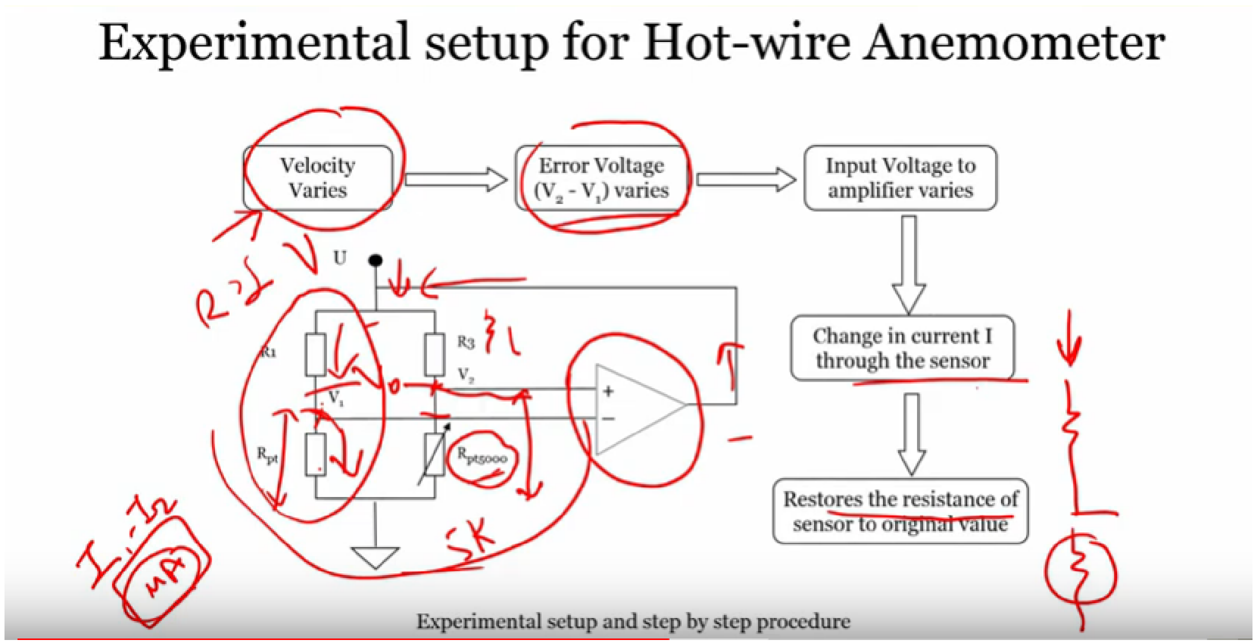

Let's see, how do we build the setup. In case we want to measure the anemometer, like I mentioned velocity varies, the output and then, voltage V 2 minus V 1, this is V 1 at this point and this is, V2. V naught is the difference between V 2 and V 1. So as the, so this is the or error voltage. The error voltage varies with the fluid flow or the velocity, how do you leverage this parameter in an electronic module? That is width and increase in velocity, there is a change in resistance, if there's a change in resistance, the amount of current flowing through it varies and then, the voltage drop varies. And that is what is being used here, the error voltage increases and what you have here is, an instrumentation amplifier, the voltage that is given, the differential voltage depending on the gain of the amplifier it, amplifies the signal and then, it is fed back to your bridge circuit, this becomes your feedback, in order to maintain your circuit in a balanced condition. So, the change in current through the sensor, if the input this voltage varies, the amplifier gives the error voltage, the amplified voltage is given here. And then, the change in current, there is a change in current through your sensor, as it flows. Another important parameter here is, you see this becomes a sensitive part of the bridge, because as your load varies, your R here varies.

So what happens, it has to be highly sensitive and the current that is flowing, even minute, even the microampere change or the, the, the minute of resistance change, has to be captured, so how does this happen, so you need to direct all your current here, even if there is a change in current, from i1 to i2 and if that change is in micro amperes, you still have to capture that value and only then you will be able to balance your bridge. And that is the reason, why this part of the bridge, uses a higher resistance. So that the current is directed towards your, more sensitive area of the bridge and that is why, you who you have a Platinum 5,000 or the 5k, which offers a higher resistance and then, this circuit becomes more sensitive, even to small changes in your load and the bridge remains balanced and you could get accurate results. And then, this restores based on the amount of excitation current that is driven into your resistor, it restores the resistance of the sensor, again to its original value. Now, this was the details about, how do you set up the entire circuit. Because, you want to measure the velocity of air, flowing through a chamber. And how do you measure and, and what is the different electronic, electronic blocks, this was a details about it.

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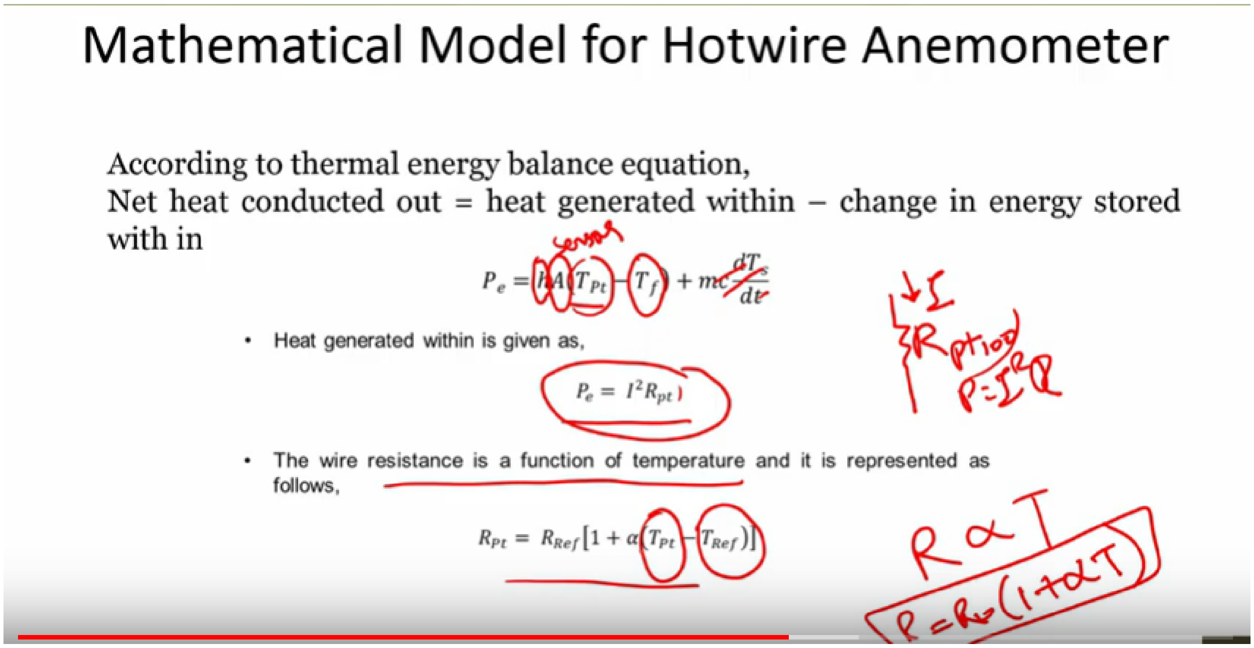

Getting into the details about, the mathematical model for the anemometer. So, this is the heat transfer coefficient, which depends on the type of fluid, A is the cross section area of your sensor device or the heater element here. Here, TPT is the temperature of platinum and TF is the temperature of the fluid. Let's ignore the term, for now in order to have, a better understanding on the mathematical model. Now, there you know that the amount of heat that is generated, through a resistor R when a current I is fluing through it. So, what is the amount of heat that is generated or the power is nothing but, I square R. R here is R Platinum. So, we are using a PT hundred. So, this is the power that is being generated when, the current I flows through this, Junction and you need to know, what is the heat transfer coefficient, of the fluid when you're flowing. So this was the I square R and then, the resistance is a function of temperature. The major parameter of an RTD, R is proportional to change in temperature and this is the equation. So, R is equal to R naught into 1 plus alpha T. So this is standard equation and in this case, we have the temperature of platinum wire, the reference temperature and this is the thermal coefficient.

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Mathematical Model for Hotwire Anemometer

- The heat transfer coefficient h is a function of fluid velocity Q according to King's law,

$$h = a + bQ^n \qquad \boxed{Q}$$

where a, b and n (approx. 0.5 for air) are constants to be determined experimentally and Q is the fluid velocity

- Under static thermal equilibrium with surroundings, equation 4-1 can be given as

$$I^2 R_{pt} = \boxed{hA(T_{Pt} - T_f)}$$

- Combining above equations, to eliminate the heat transfer coefficient h,

$$a + bQ^n = \frac{I^2 R_{pt}}{A(T_{Pt} - T_f)} = \frac{I^2 R_{Ref}[1 + \alpha(T_s - T_{Ref})]}{A(T_{Pt} - T_f)}$$

Now what happens is? The heat transfer coefficient is a function of the fluid velocity. Ideally, what do you need? You need to know the velocity of the fluid and how do you get the parameter Q? Hence, equating the two I square R and the equation here, substituting for the other parameters and then eliminating heat transfer coefficient, as shown below

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Mathematical Model for Hotwire Anemometer

- Instead of measuring current it is easy to find the voltage across resistance of platinum wire. Hence the above equation can be rewritten as,

$$a + bQ^n = \frac{V_{pt}^{\ 2}}{R_{pt} A(T_{Pt} - T_f)}$$

- And the V_{pt} can be written as,

$$V_{pt} = \frac{R_{Pt}}{R_{pt} + R_{150}} V_o$$

And

$$V_O = A_{OL}(V_{Pt} - V_{Pt5000})$$

- The above equation can be rewritten as follows,

$$a + bQ^n = \frac{V_{Pt}(V_O - V_{pt})}{R_{pt} A(T_{Pt} - T_f)}$$

you would get an equation and again, you are substituting here, because measuring current instead of measuring current, it becomes easy to find V naught that is the error voltage. And hence, you replace the parameter I with V, in the previous, previous case and this is your equation. Substituting further you would get an equation, where the fluid flow is directly proportional

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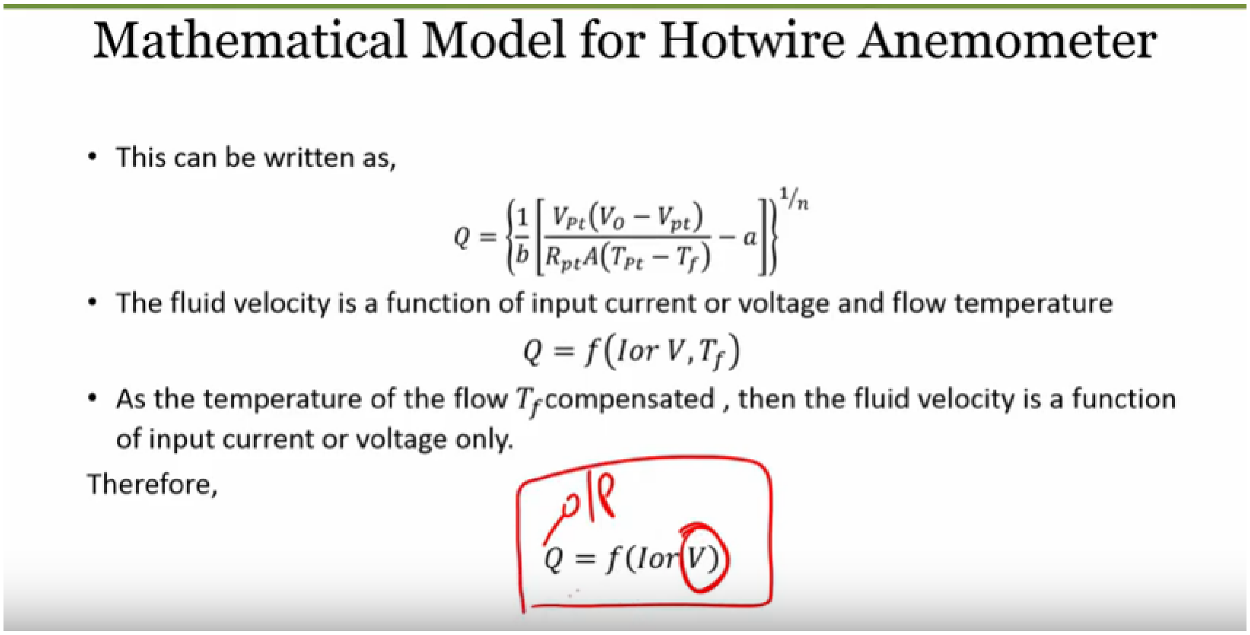

to the rate at which, the error voltage. Hence, what is important you need this output and then, what do you have? You have the error voltage. So this is the relationship between, the rate at which fluid is flowing and, and how it is related to the current or current and voltage.

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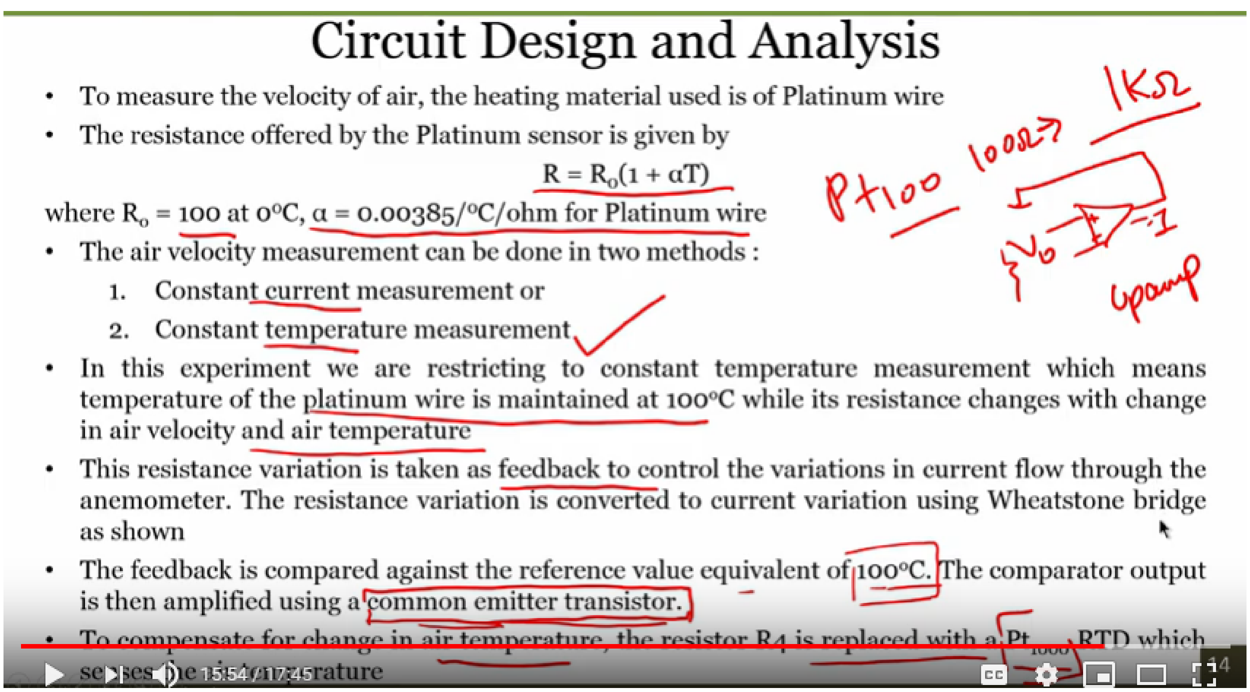

Like, I mentioned the resistance offered by, the Platinum sensor is given by R is equal to R naught 1 plus alpha T. The standard where R naught is 100 Platinum PT hundred. So, its 100 ohm at 0 degree Celsius and the thermal coefficient of platinum is 0.0038 5 per degree Celsius per ohm. So, these are the parameters, which you have to consider, for our case we're using platinum 100, so make sure you identify what are these parameters, when you're substituting them in your bridge circuit. Now, the velocity measurement, like I mentioned the two methods, constant current, constant temperature and here, we focus on the constant temperature measurement. The temperature of the wire remains at hundred degrees Celsius, but in our case since we have a compensating; it remains at the ambient temperature conditions, if you are using it, in the outside ambient environment. And any change in resistance, with the velocity can be leveraged. And then, you know what is the role of a feedback, the feedback controller? Like you see in the instrumentation amplifier, the, the V naught is given to the amplifier and the differential error voltage is fed back to your bridge circuit. The feedback has come, compared against, the reference value equivalent for, of 100 degree Celsius.

So this is a more generic case, but not always true, when you are experimenting in an ambient condition. So, the comparator output is then amplified using common emitter transistor, you haven't seen the role of a transistor, we've just seen the instrumentation amplifier, of certain gain directly feeding the bridge circuit. However, you know that this cannot drive heavy currents and that is, when the common emitter transistor comes into picture. But, this again becomes a choice, depending on the type of op amp, your using in your circuit and if it can support and drive heavy currents, you need not use the common emitter transistor. In order to compensate in air temperature, the R4 is replaced with PT thousand RTD, which senses the air temperature, like I mentioned, it need not be zero degree Celsius always we are measuring in outside environment and that is when, we have this PT thousand one kilo ohm, the reason behind the resistance being higher, than the heater that is 100, 100 ohm has been detailed to you, previously. So, the compensator a circuit, what we would be using is here is a PT 1k or it could even be a PT 5000 RTD.

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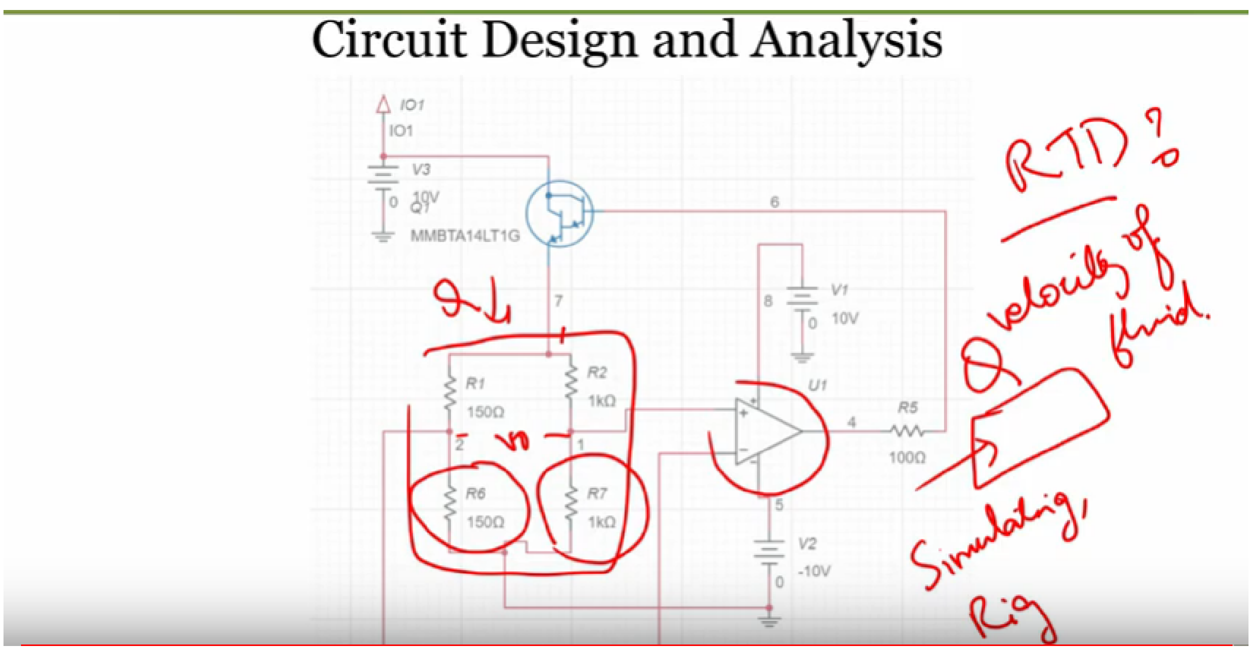

So this is the final circuit. The bridge circuit here, this would become your heater, the temperature compensation circuit that the difference in error voltage, being given to the instrumentation amplifier here. And then, the amplified signal is fed through your transistor and then, given back, in order to maintain the difference between the two voltage, to minimal. Let's discuss more about, how can you recap the circuit, let's see how the different parameters, the change in resistance and the change in temperature, the rate at which the fluid flow, all of this affects the V0, in the bridge circuit, by licking up this, simulating this and then, dragging the entire circuit, on the board and let's experiment and get a hands on, of how the anemometer can be used to understand, the rate at which the fluid is flowing. That is the velocity of the fluid. So, this was the basics about, what is RTD? And how is it different from thermocouple? And what should be the resistance? Where does the compensate research it goes? And what are the different types of anemometer? And how we can get into the details of, the constant temperature anemometer, in our next module. Thank you.