Advanced IOT Applications
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Lecture – 37
Air quality: System design - part 1

So, let us move on now further and try and look up the way one can wire up a N O 2 sensor, N O 2 and C O oxidation reduction right, N O 2 O 2. In fact, it is a cross sensitive to so many gases. In fact, I will show you one data sheet where you can measure other hydrocarbons as well. So, mainly N O 2 and C O, but we can concentrate for the moment, just keep it simple, you are interested only in N O 2 measurement and just let us concentrate on that part. How do you tune when you buy the sensor, what are the key documents that you have to look up so that you can tune the sensor. That is the key question that I wanted you to get exposed to.

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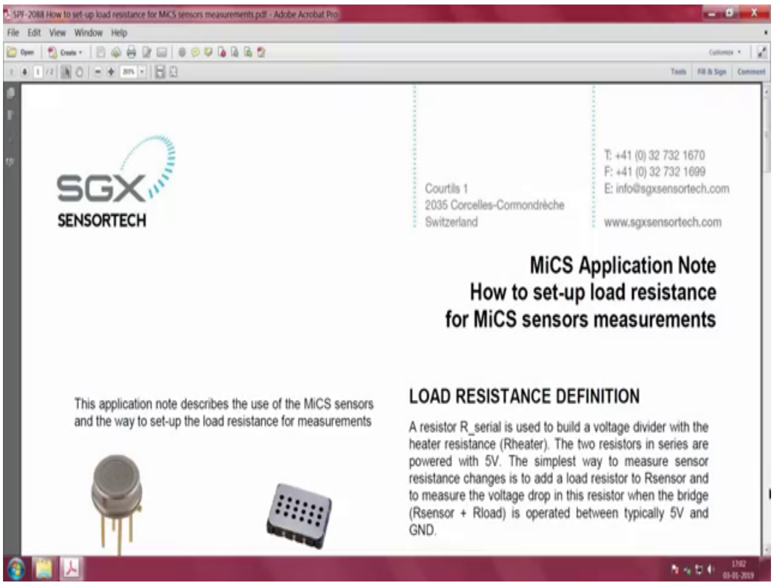

So, let us go to this SGX sensor tech right.

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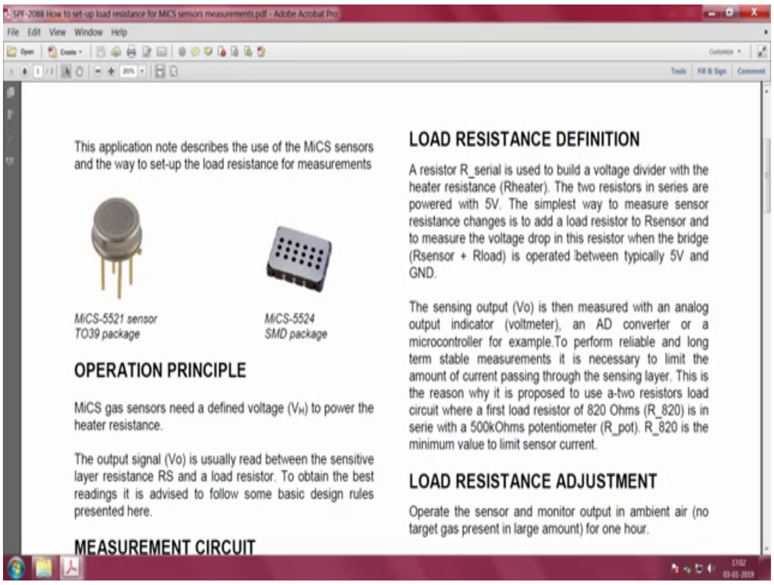

I have expanded it to some good percentage. So, you will see that you will get it in two form factors, you will get it in this form factor. Let me show it with this.

So, it will give it with this form factor as well as in this form factor. And please note that all efforts in say semiconductor sensors is trying to get to that value of what is the change from the base right, change in what change in resistance from the base. So, R S by R naught, R naught is the value that you have derived under normal circumstances in clean air condition you got a value in the absence of N O 2 0, nothing no value of N O 2 there, you got a value of R naught.

And after, that you measured the change in resistance and that change in resistance essentially is actually increasing in resistance and that u is a proportional to the p p m or p p b. If it is N O 2, it should not even exceed if you ppb right should be some 20, 30, 40 ppb or so. So, that is the range in which you want to make a very very accurate measurement.

So, that change in resistance is what you are looking for. So, in other words, here is a representative circuit. Do not ever think that if you get a representative circuit that just rigging up a representative circuit is going to take you very far. I do not think that will happen. If you are serious of working on N O 2 using mix sensor, it is good for you to buy an evaluation board which is are given out by sensor tech.

They would have adjusted, they would have parameterised, they would have calibrated and perhaps given you something that you can measure off the shelf directly. Therefore, any effort in the direction of making your own air quality sensors board means, buy one that is pre calibrated, buy one that you want to make and put them together, co locate them and calibrate the one, that you want to calibrate that you do not know you want to calibrate with respect to a known reference sensor which gives out some value of N O 2 or whatever.

So, this has been my effort in the lab as well because we have not gone yet into any place where you would have a climate chamber, you would control the humidity, you would control the temperature right and so, T P H, I mentioned this temperature, pressure, humidity and effect of the baseline shift because of this is well discussed now. So, we did not go we that is a, it is an expensive affair for you to go and set up all that just for making one simple measurement.

So, we strongly recommend by a standard board and start working with it and ensure that when they give you the standard board, it is already pre calibrated right. They would have given you a calibration graph and you can actually write your code and monitoring and all that using that standard stuff.

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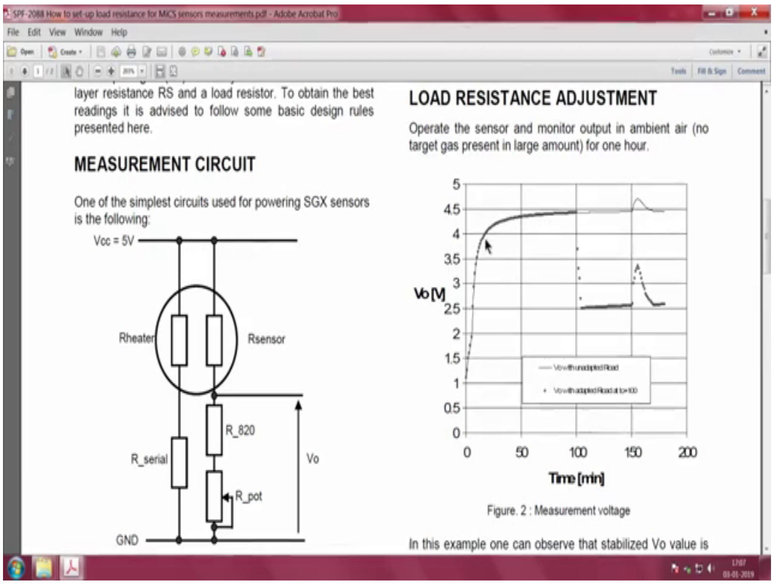

So, let us see about this. So, essentially, this data sheet is actually talking about that. The left side of the measurement circuit is pretty straight forward. You can see this part right.

This is what you must put one limiting resistor R serial and R heater. Do not confuse this with this right side one at all. This is the one that is required for heating, this is meant for heating. So, use it for heating. And this is the one this leg is the one that is used for measurement of a particular gas.

And, what they feel is that the also you have to limit the current through this wing. So, they will give you some reference circuits and they want you to adjust this V naught under low gas condition to exactly the V cc by 2; that means, you should be able to get off something like 2.5 volts here, if your V cc is 5 volts so that any change will swing nicely between 2.5 and rail on the positive side and also on that negative side, it can go up to 0.

So, if you keep it in the middle is a good way to adjust as this paper is talking about how to do that adjustment and how do you ensure that values that you choose are you know essentially meeting this requirement.

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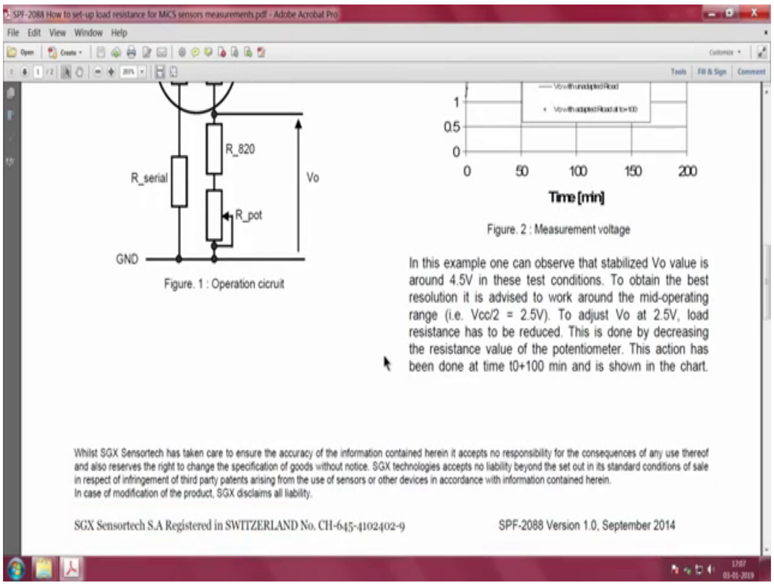

So, you can see, in this example one can observe that stabilize V O value is around 4.5 volt in these test conditions, you can see this is exactly what they have done you, this is what has been stabilized under test conditions a measurement voltage. To obtain the best resolution, it is advise to work around the midpoint range. So, even in my lab, I have this around the 4 point I think we have got it up to 4.7 or 4.8, I do not recall, but we also have done exactly this part adjusted to get you to this point. But to get good resolution, you may want to work at the midpoint.

So, you have to adjust with this potentiometer to get to that midpoint. This is done by decreasing the resistance value of the potentiometer. This action has been done at time T naught plus 100 minutes has to has been done; that means, you are to wait until this heater warms up, everything is all done and then under steady state condition, you should be able to adjust it and leave it there.

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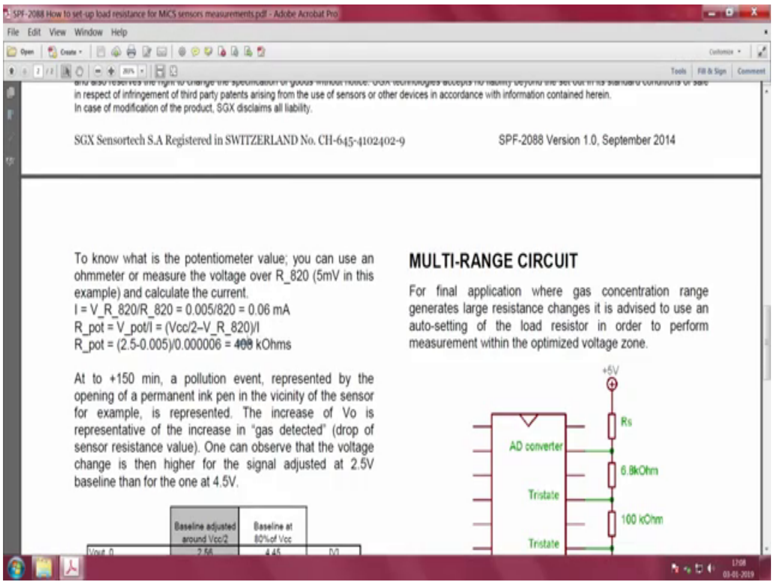

And how do you calculate that value of the potentiometer R value? Well, here is a simple expression which will give you that everything is around the Ohm's law. So, I would not elaborate that.

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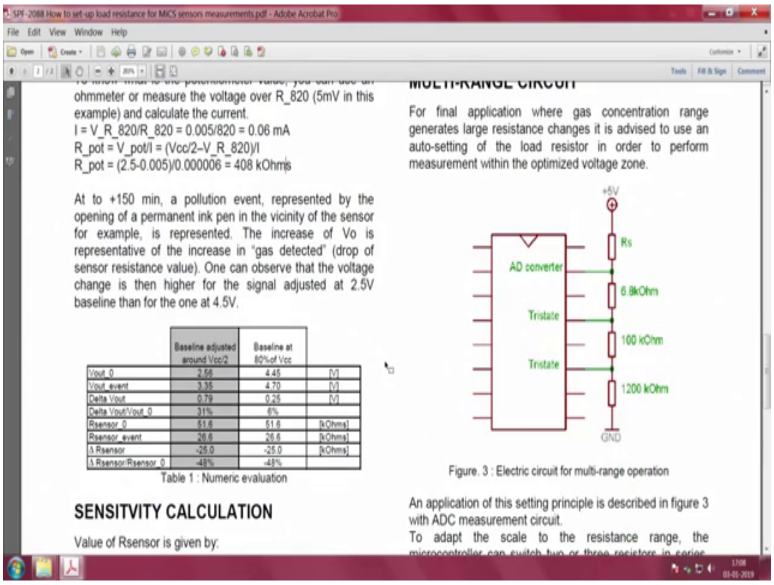

So, essentially if you do baseline adjusted around V cc by 2 or baseline at 80 percent of V cc which is 4.5 volts and 2.56 in either case, there is no problem of R S by R naught. There is really no problem, only thing is good swing you will get right and good resolution you will get.

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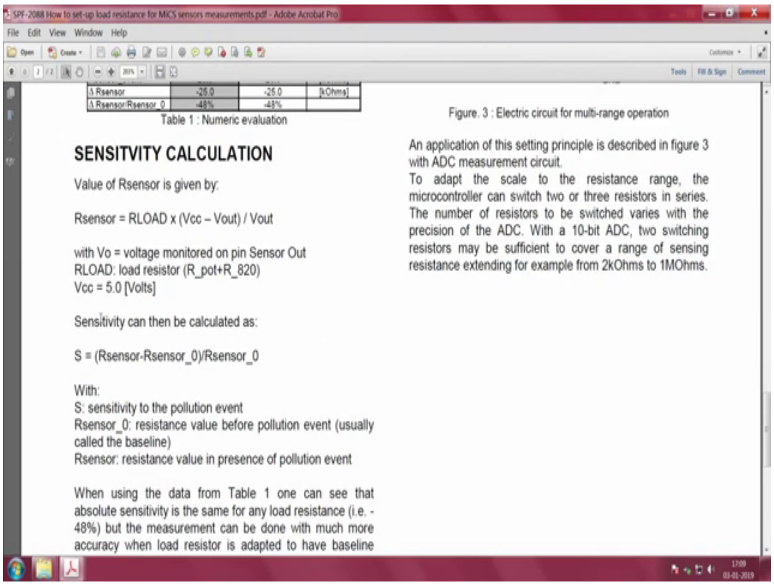

So, it is that is what he is trying to tell here, this is the way you do it sensitivity can begin calculated as R sensor R S minus R naught divided by R naught, R naught is resistance value before pollution event, R S is the sense resistance value in the presence of pollution. From table 1, so you can see; one can see that absolute sensitivity is the same for any load resistance. There is no problem of absolute sensitivity ok.

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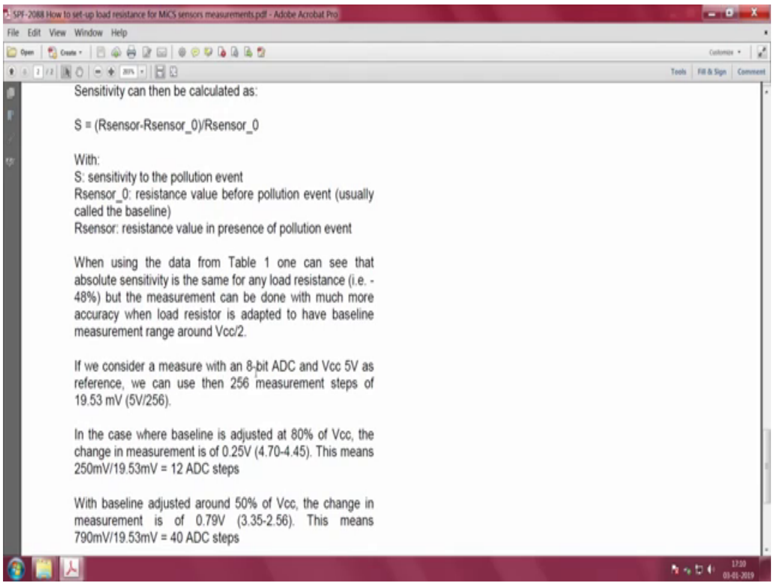
Sensitivity can then be calculated as:

S = (Rsensor-Rsensor_0)/Rsensor_0

With:
S: sensitivity to the pollution event
Rsensor_0: resistance value before pollution event (usually called the baseline)
Rsensor: resistance value in presence of pollution event

When using the data from Table 1 one can see that absolute sensitivity is the same for any load resistance (i.e. -48%) but the measurement can be done with much more accuracy when load resistor is adapted to have baseline measurement range around Vcc/2.

If we consider a measure with an 8-bit ADC and Vcc 5V as reference, we can use then 256 measurement steps of 19.53 mV (5V/256).

In the case where baseline is adjusted at 80% of Vcc, the change in measurement is of 0.25V (4.70-4.45). This means 250mV/19.53mV = 12 ADC steps

With baseline adjusted around 50% of Vcc, the change in measurement is of 0.79V (3.35-2.56). This means 790mV/19.53mV = 40 ADC steps

That is about 48 percent, but the measurement can be done with much more accuracy when load resistor is adapted to have baseline measurement range around V cc by 2. So, that is essentially what he is saying, while absolute sensitivity is not compromised better accuracy is possible if you keep it around V cc divided by 2. If we consider how to you want to do that, you have an 8 bit ADC you have 5 volts, you know exactly what you will get for every step. You will get 256 steps because this is an 8 bit ADC and each step will correspond to 19.53 millivolts which is quite straightforward to calculate from here.

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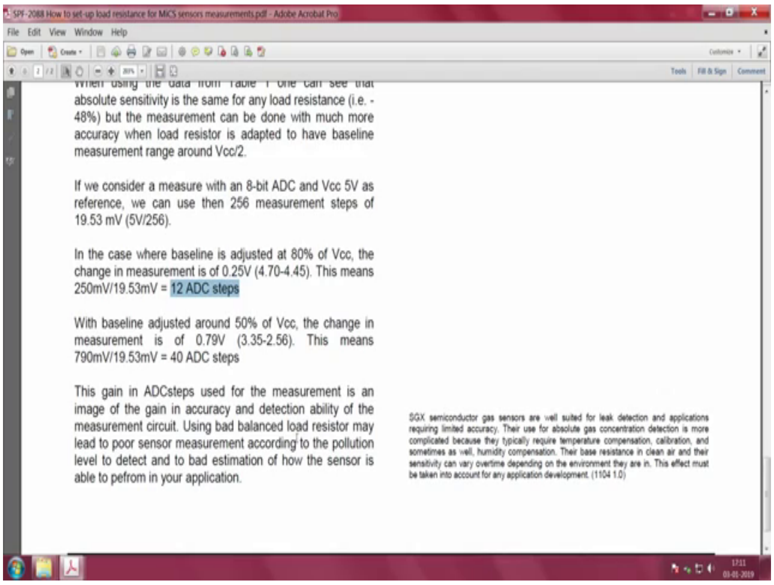

In the case of 80 percent V cc, you will only get 12 ADC steps, you can see that is pretty obvious which means because you are already there 4.70 to 4.45.

So, if you do that, you will only have now, this means that you will only get about 12 steps; obviously, if you are much higher closer to the rail you will not be able to closer to the power, power supply power supply voltage, you cannot get much range to play with. And therefore, you will get only 12 ADC steps. But if you put it back to 50 percent of V cc, you will get, you can go from 2.56 to 3.35 and you can get a step of 0.79 right. This means 790 millivolt by 19.53, 19.53 millivolt which is 40 ADC steps. So, your accuracies are different depending on where you put this baseline point um, essentially the whole you know explanation is about that.

So, this gain in ADC steps used for the measurement is an image of the gain in accuracy and detection ability of the measurement circuit. Using bad balance load resistor may lead to poor sensor measurement according to the pollution level to detect and to bad estimation of how the sensor is able to perform in your application. So, it is all about how you use this data sheet to your advantage for your given scenario. So, in our case, what we did was, we wanted to measure ambient N O 2. So, our was exactly matching this measurement voltage figure 2 and we had this little margin to go up to a certain threshold point and we had very few ADC steps and so on.

But we were able to get the detection quite right. So, we were able to measure even 20 ppb and then going up to about 40 ppb, very small change in N O 2. Look appears that, you can still do because the overall sensitivity is never pull down even in spite of any point you are with respect to this V o. So, that is about this application node.

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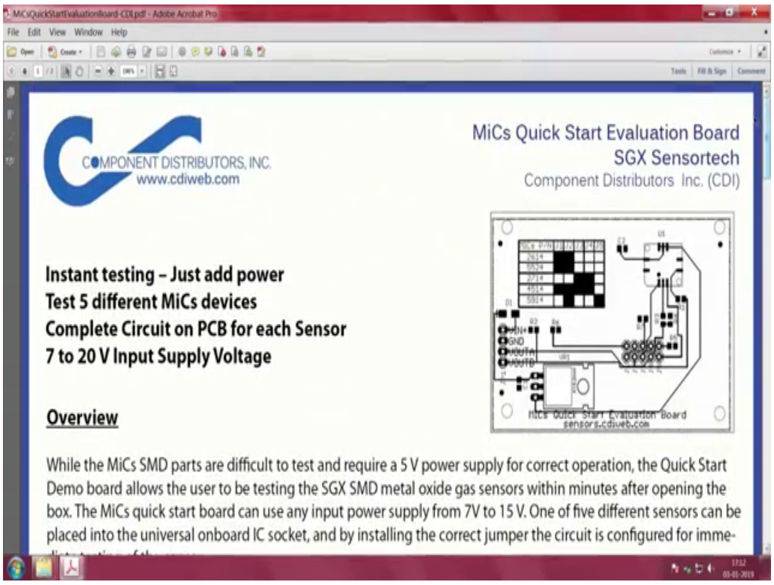

You may also actually look up the kit which is given to you which would be a nice starting point for you to add power, test five different MiC’s that is MiC quick start evaluation boards from them, all right.

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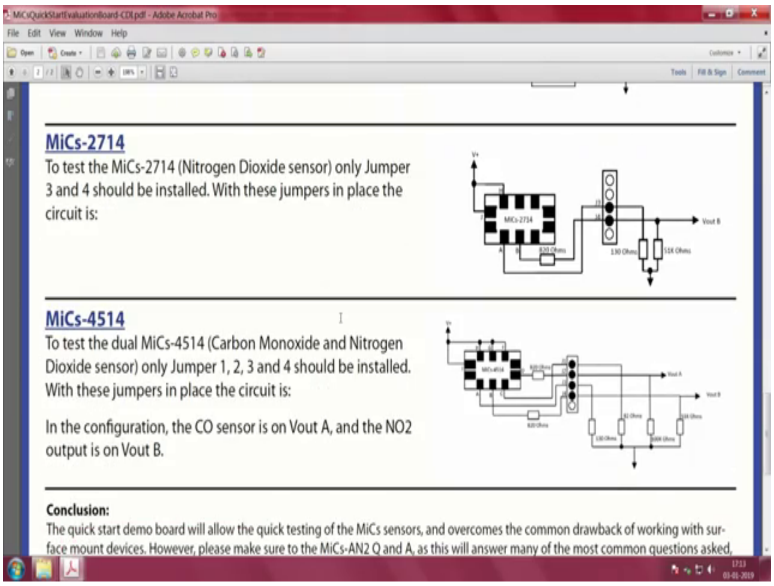

And he gives you a kit whereby you could essentially connect MiC's 4 5 1 4. You can see it is a dual mix 4 5 1 4 C O and nitrogen dioxide by changing some jumper positions you should be able to measure both right.

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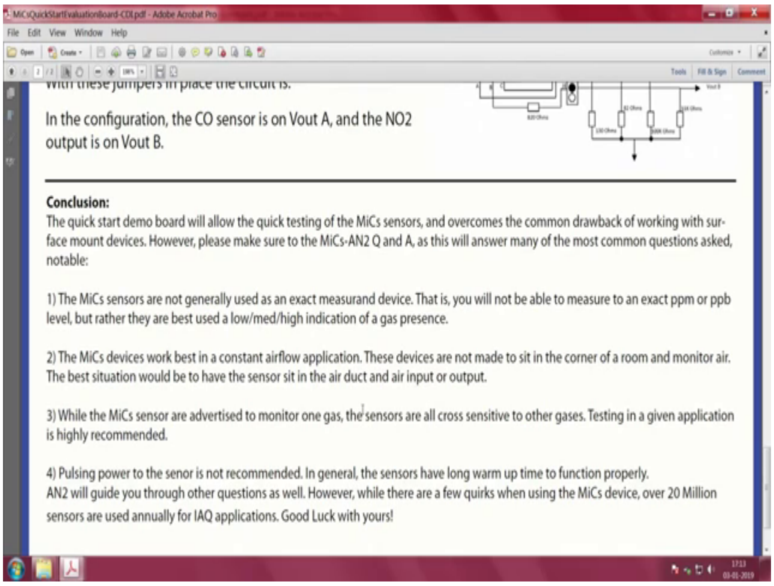

So, the conclusion is very interesting and I want you to spend some time on this. Ok, leave the first one just the top point but number one is a very interesting thing. MiCs sensors are not generally used as an exact measurement device which is a very clear indicator. So, nicely written, they are saying they are not making any tall claims about semiconductor sensors being very accurate.

They say it is not really meant for 21 ppb, 24 ppb, you cannot do that. It is that is not going to work it is not meant for that kind of very accurate measurement and I feel it is also not required when you are doing ambient measurement. You roughly want to know low, medium, high right. So, that is exactly what he writes here, that is you will not be able to express in p p exact ppm and ppb, but you will basically get low medium and high ok. That is point number 1, point number 2.

So, beautifully written again going and summarizing everything that we have been discussing, do not put a N O 2 sensor and put it in the corner of your room if you are doing indoor or outdoor as well. It is if there is no flow, there is no accurate way of measuring air quality at all. Please note this. I mentioned to you already, 1 litre per minute, 0.5 litres per minute to 1 litre per minute looks good appropriate for any measurement.

So, you have your ducts and all that we using some simple pumps so that you will be able to make a nice airflow across the sensor so that a measurement is adhering to the requirements. Also, when you calibrate think like this when you calibrate, you will have a climate chamber and you will be a passing gas also at a certain flow right.

Now, that same flow while during calibration if you are maintained let us say 0.5 litres per minute, it is always nice to make a measurement you know away from this calibration part also in the same range. It is, but logical to think that way. So, it is good to have a pump, which will allow you to suck the air at a particular rate which is adhering to almost the same value that, you would choose when you are calibrating them in a lab environment. So, that is the second point that he says. The third point he is saying is while it is advertised for N O 2 and C O, oxidation reduction phenomena that happens, be very sure that it is going to be highly cross sensitive to.

So, many other gases and therefore, you must ensure that you are doing testing, given the fact that you are interested in only one type of gas that you want to detect, but keep this in the back of your mind, he says this. The fourth point he says is do not pulse no pulse power thing you should recommend and the sensors require a lot of warm up time.

So, ensure that, you just do not think that you buy it from the vendor put it in the system and then say it should start measuring. That would not work, you even there are recommendations on how much warm up time should be. You must give before the baseline is settling down. Once the baseline settles down, you know that the heater is fine, the sensor is fine and after that if you pass any gas, it should be able to measure quite accurately.

So, a final punch line is very good. I want you to look at this it says. However, while there are a few quirks when using MiCs devices over 20 million sensors are used annually for indoor air quality applications. So, which means, in spite of all these problems of not be able to measure accurately and all that, MiCs indeed is a maybe it is a good sensor to try. I am not recommending MiC's, I am just took this as an example you have.

So, many other vendors and I think it is a good to perform a chart which has all the sensors one by one. This is semiconductor there is an equivalent N O 2 for from for electrochemical application. So, you may want to look at that because it is much more linear and you can do a lot more things. But can MiCs also do anything very nice, can you do get some linear relationships at least over a smaller range, they answer appears to be yes. And then, now let us look at the other paper which finally, summarizes the whole system. So, it is saying about so let me go there and so we have done with this.

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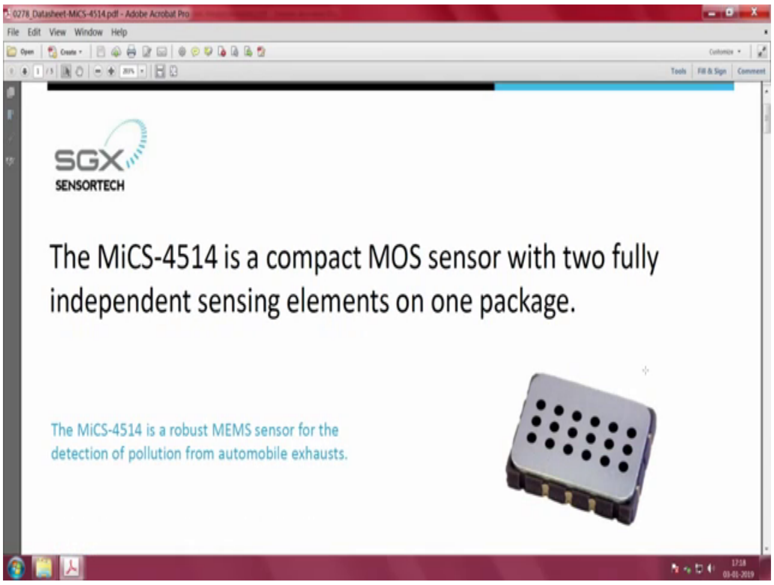

So, let us look at this final data sheet. In this data sheet, it says it is a compact mass sensor with fully independent sensing elements on one package.

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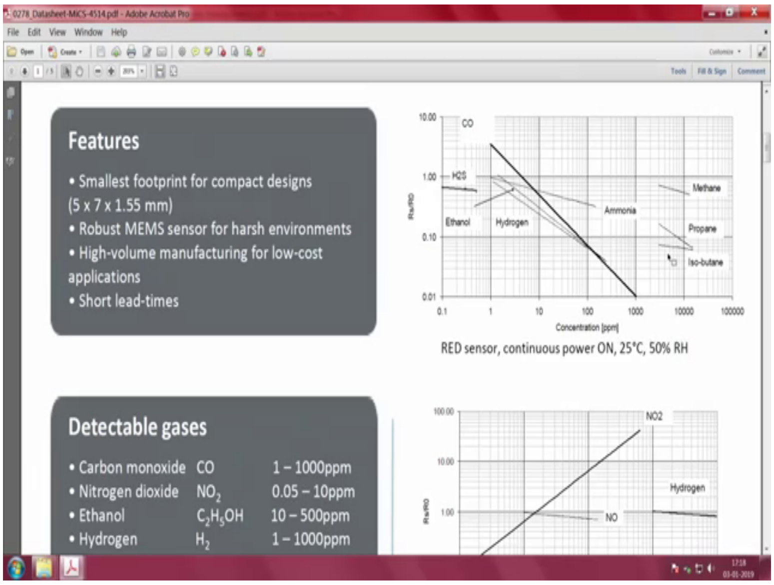

Its robust MEMS sensor for detection of pollution from automobile exhaust, but it is not limited to just automobile exhaust, small footprint, robust MEMS, sensor. Look at the top picture you have, so many other gases it is detecting.

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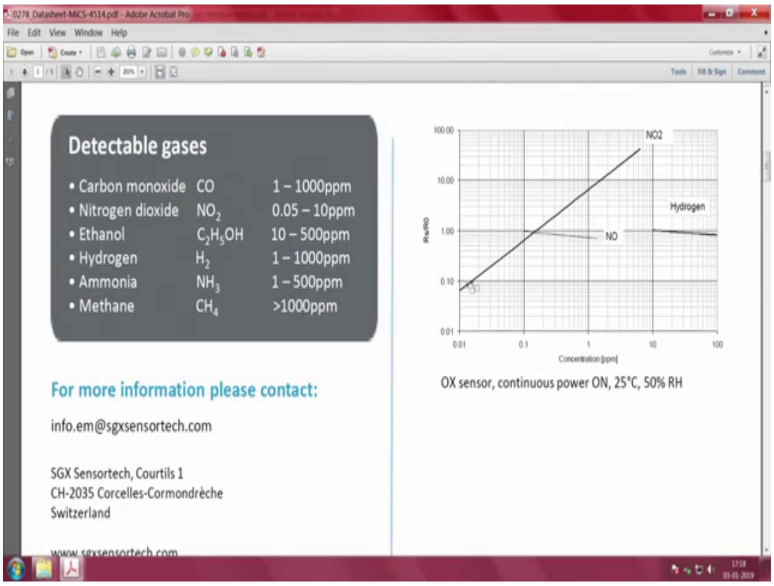

So, I would prefer you to close your eyes and we move directly to look at this N O 2 right.

So, N O 2 you can see that it is a logarithmic graph um. It is rising up log graph you have R S by R naught, this is what you are looking at from the sensitivity perspective and you can see N O is going like this and N O 2 is fairly. Although, this is a you have to note that this is a log scale log linear, perhaps this measurement is done for continuous power on. Look at what all he has put down as a spec T P H, if you see. I think he has taken pressure as 1 atmosphere.

So, leave that; P is done, temperature is 25 degrees, H is 50 percent R H. So, now, you go back and look up, what should I do when I have to calibrate this in a calibration facility? What will you do? You have to get a climate chamber you have to request for points so that you can write your if you want to creating a linear regression of the points, you have to get it for a given temperature for a given humidity. Assuming that pressure is constant, we will do it for different p p ms. So, you have different p p ms for the same p p ms that you have chosen or p p bs. In the case of N O 2, let me be saying p p b.

Let us say you want to measure 20, 40 and 60 ppb. These are the three concentrations you want to pass from the gas cylinder by mixing it with air and all that, you are passing it, but at what temperature you want? So, therefore, what will you do you will say 20, 40, 60 at 25 degrees of so much humidity, 50 percent R h, one range. Then again, 20, 40, 60 at 50 degrees with the same R H perhaps, one more range.

Then again, 20, 40, 60 with 70 degrees and perhaps the same humidity or maybe increase humidity. So, combinations are many, right. Therefore, and every time you pass gas, you make a measurement and you get these points. You can you put them and then create a regression equation, all that clearly indicates that it is very repetitive and you should be able to sort of device your own algorithm on what are the key points that you want to measure for different temperature, pressure and humidity a values.

So, it is pretty expensive for you if you go to a calibration lab to do all these repetitive tests and arrive at anything useful. One solution which I can think of is if you are buying from a particular vendor, a let us say you are buying from sensor tech which is this MiCs 4514 N O 2 semiconductor sensor, you could ask them for the as I said the board which is which has a pre calibrated sensor in it.

Then, for you to co locate them and do some measurements becomes easy. All I am saying is that, if this let us say the pre calibrated one is already indicating 30 ppb, then you have the option of trying something in the lab and then taking that same board and going to some very busy traffic junction just to see, if there is a increase in N O 2 and the standard one is measuring let us say I do not know maybe 70 ppb.

And now you have to adjust this R value such that you will also reach to that value of maybe that is whatever 70 or 80 ppb that you have set. So, that way you can get points yourself calibrated and then perhaps you know sort of put it into a lookup table and then transmit a value based on the R S by R naught that you would actually obtain.

Essentially, that is what you could do all by yourself, but professional way to do it is to take it to a calibration facility gas calibration facility which has mass flow meters and it has a climate chamber and then there is a mixing unit and there is dry air and then there is the concentration of nitrogen dioxide that you want to mix together and so on and so forth. So, indeed all this is what you should be doing.

Let us look at what are the detectable gases. You see it measured C O up to 1000 ppm, nitrogen dioxide up to 10 ppm, ethanol C 2 H 5 O H is up to 500 ppm, hydrogen is up to 1000 ppm, ammonia it can measure from 1 to 500 ppm and methane C H 4 greater than 1000 ppm. So, all these are possible from this MiCs 4514 sensor.

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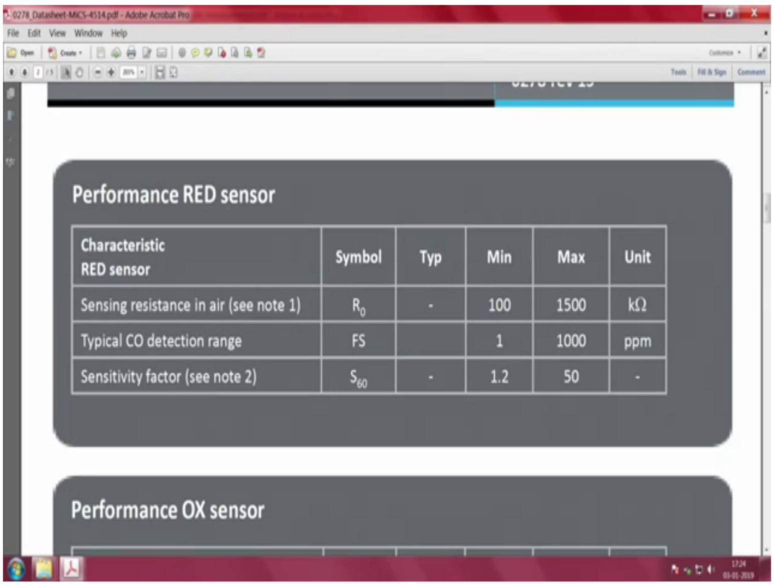
Performance RED sensor

Characteristic RED sensor	Symbol	Typ	Min	Max	Unit
Sensing resistance in air (see note 1)	R_0	-	100	1500	kΩ
Typical CO detection range	FS		1	1000	ppm
Sensitivity factor (see note 2)	S_{60}	-	1.2	50	-

Performance OX sensor

It appears a pretty cross sensitive to several other gases which is expected of MiCs sensor. So, when you say red here it means reduction. So, when you say reduction, what are you reading off? Your reading C O, you should just make a quick note of that this is C O.

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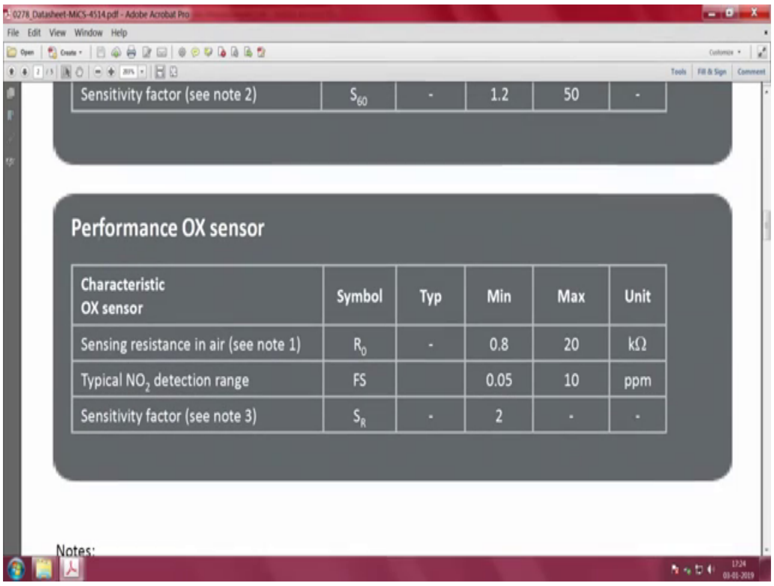

Sensitivity factor (see note 2)	S_{60}	-	1.2	50	-

Performance OX sensor

Characteristic OX sensor	Symbol	Typ	Min	Max	Unit
Sensing resistance in air (see note 1)	R_0	-	0.8	20	kΩ
Typical NO_2 detection range	FS		0.05	10	ppm
Sensitivity factor (see note 3)	S_R	-	2	-	-

Notes:

And if you say oxidation O X, then you are reading N O 2. This is typical of all air quality sensors ok.

So, you can see that, it can read up to 10 ppm if it is typically N O 2 under O X performance of O X which is oxidation. Sensitivity factor is 2 in one case, sensitivity factor is minimum is 1.2 in the case of reduction.

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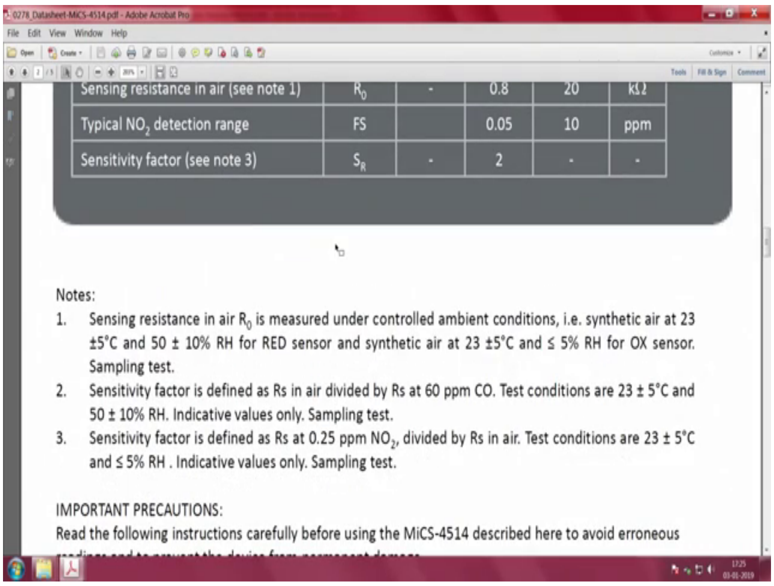

Sensing resistance in air (see note 1)	R_0	-	0.8	20	kΩ
Typical NO_2 detection range	FS		0.05	10	ppm
Sensitivity factor (see note 3)	S_R	-	2	-	-

Notes:

1. Sensing resistance in air R_0 is measured under controlled ambient conditions, i.e. synthetic air at 23 ±5°C and 50 ± 10% RH for RED sensor and synthetic air at 23 ±5°C and ≤ 5% RH for OX sensor. Sampling test.
2. Sensitivity factor is defined as Rs in air divided by Rs at 60 ppm CO. Test conditions are 23 ± 5°C and 50 ± 10% RH. Indicative values only. Sampling test.
3. Sensitivity factor is defined as Rs at 0.25 ppm NO_2, divided by Rs in air. Test conditions are 23 ± 5°C and ≤ 5% RH . Indicative values only. Sampling test.

IMPORTANT PRECAUTIONS:

Read the following instructions carefully before using the MiCS-4514 described here to avoid erroneous

So, what are the important points here? Sensing resistance in air is measured under control ambient conditions um; that means, R naught, look at the trick that you have to do. You have to get to R naught. So, to fix this R naught and the way to fix this R naught is to send synthetic air at this temperature, 23 degrees plus or minus and 50 percent relative humidity for reduction sensor and synthetic air at 23 plus 5 degree, less than 5 percent relative humidity for oxidation sensor. You want to, do N O 2 measurement do this, pass synthetic air.

What is synthetic air, just simple air of nitrogen and oxygen combined 78,, 22 that is all just this much is sent. So, at 78 and 22 correct and you mix both of them put it, put the humidity to 5 percent right and just send that air then you get your R naught. That is what your baseline is.

Then, you have the sensitivity factor which is defined as R S in air divided by R S at some ppm. You can see this 0.25 pm N O 2 divided by R S in air ok. So, sensitivity factor is defined as R S at 0.25 ppm N O 2 divided by R S in air. Again test conditions are given 23 plus minus 5 degree Celsius less than 5 percent relative humidity, indicative values only you have to do, some sampling test and so on.

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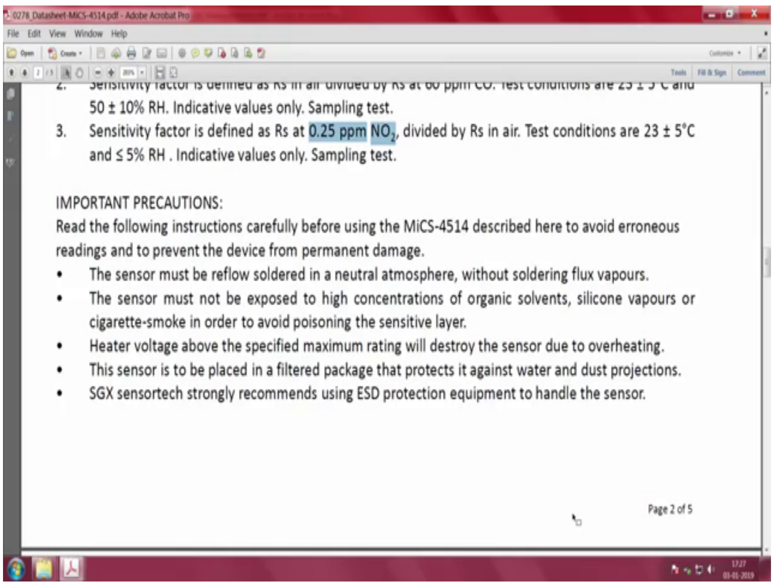

And he gives you precautions of ensuring that MiCs should not be destroyed. How should you ensure that? No smoke, cigarette smokes and all that you should not you use manual soldering you should do some reflow soldering right and heater voltage you should not exceed maximum rating and so on.

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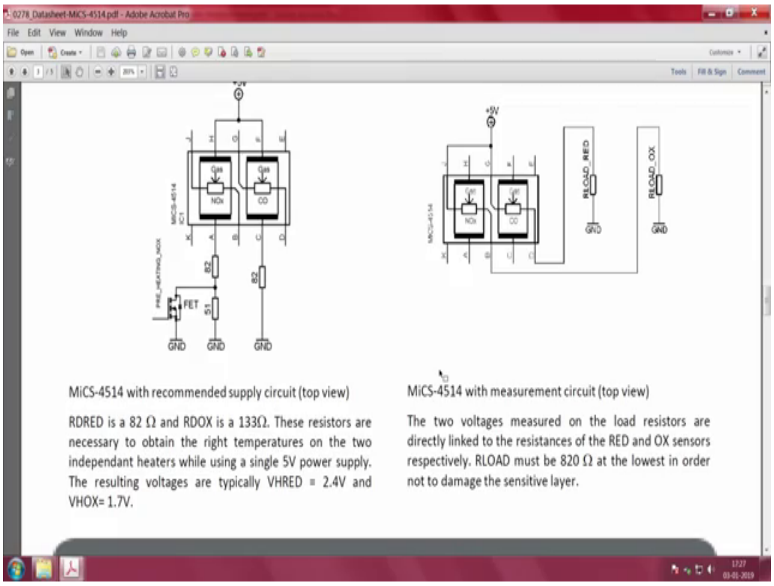

So, you must take care of ESD and all that. So, you can see that this is the datasheet he has provided you and with recommended supply circuit is given you.

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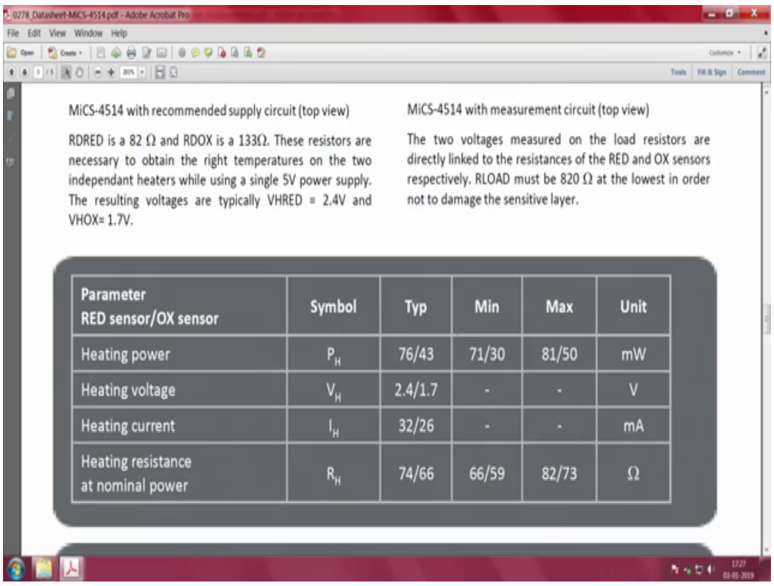

Parameter RED sensor/OX sensor	Symbol	Typ	Min	Max	Unit
Heating power	P_H	76/43	71/30	81/50	mW
Heating voltage	V_H	2.4/1.7	-	-	V
Heating current	I_H	32/26	-	-	mA
Heating resistance at nominal power	R_H	74/66	66/59	82/73	Ω

So, this is for reduction and oxidation sensor both. He has given you the heating power, heating voltage, heating current and heating resistance at nominal power everything is mentioned. Read the datasheet accurately and set up your system to measure the N O 2 as well as if you are configured for C O, you configure C O separately ok.

So, I could go on like this, but it is important for us to put a hold put a halt to all what we have been discussing now and take a back seat and say what did we learn in this process of this complete module. What we have learnt is the importance of air quality monitoring and the challenges that you have in making such a measurement possible in reality using I O T sensors because the selection of component itself is very very critical. There are so many parameters that you will have to choose and get into the detail of how to choose, what to choose?

Should you choose electrochemical, should you choose semiconductor sensors and what is the range you want to measure and to what accuracy you want to measure, how accurately you want to measure this ? All these are something that we have covered. Of course, we know where pollution is coming from contribution of automobiles is known right, contribution by solid fuels is known now we know a little bit that it comes from soil solid fuels from automobiles, automotive applications, energy generation, stable agricultural residues and so on and so many things that really motivated us to study this a problem.

So, let us now finally, concentrate on can we put everything together and put up a nice demonstration of this system ok? You may not be able to calibrate because calibration is would be very difficult for us to show you. Although, there are efforts to in that direction, you may have to look for a standard lab which will give you will allow you to build a chamber for your sensors and that as a chamber can be used for calibration purposes.

Nevertheless, it does not stop us from discussing what are the key you know decisions, that you have to make before even you choose a sensor. Let us do that and then finally, let us wind it up with a nice demonstration. I will explain the demonstration setup to you and we will see what are the key results that one can get from them.