Advanced IOT Applications
Dr. T V Prabhakar
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture – 36
Air quality: Overview of system design

So, we should take a nice example of a semiconductor sensor, understand its application note and so, you will get a feel for how the whole sensor should be laid out on your system so that a measurement is possible, ok. So, that is our next immediate goal; slowly, we have to move towards system design of air quality sensors.

So, I will point you to one semiconductor sensor which is quite popular and you know that previous paper that we were looking at calibration mentioned so many sensors, alpha sensor was there then sensor tech SGX 4514 was mentioned and so on, right. So, I have taken SGX 4514-MICS MICS MICS-4514 semiconductor sensor which has the capability to measure NO 2 as well as CO, both it can measure. There are two heaters inside and one heater is for measuring of NO 2 and the other is for keeping the system warm and then start measuring the target gas of interest.

So, let us take that as a one example and build on top of that and see what are all the things that, you will have to get in into your system before you actually build a full-fledged system, ok. That is just an example and if you know well how to do with semiconductor, then it is easy also for you to prototype with a electrochemical because amperometric method can be applied and you put a trans conductance amplifier and I think you should be able to also measure the from output coming from a electrochemical sensor to where that, there it is current driven in the electrochemical and here it is change in resistance which you are measuring directly actually it is voltage and then you find out the R value never mind.

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So, so, let us point to this frequently asked questions of MiCS SGX sensor tech a Gas Sensors, small little one. The reason why I also chose this is also because of the fact when I showed you the PCB I showed you a very small little tiny system on board and that indeed use the SGX sensor tech. So, that is the also the reason why I chose it, we have some experience working with it.

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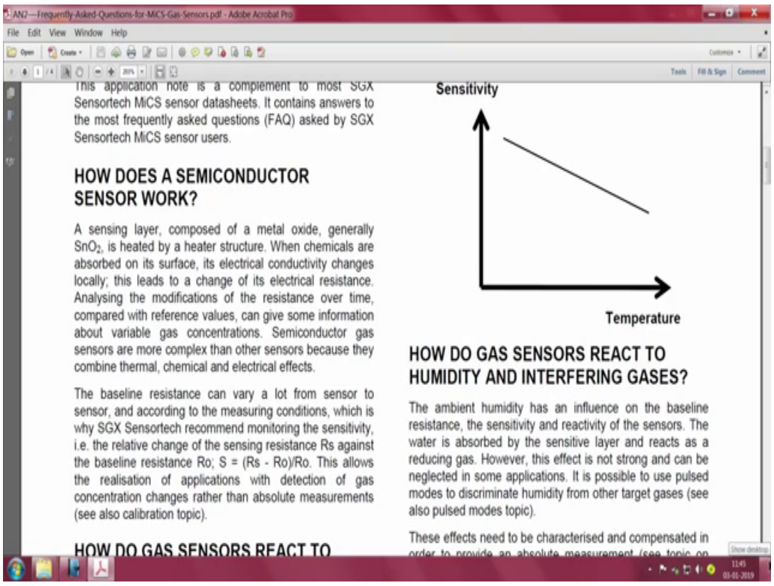

How does it work? You know it well now it is metal oxide SnO 2 is the material and you have a heating structure is heated by heater structure and once the chemicals are absorbed there is a change in electrical conductivity, leads to change in electrical resistance. Analysing the modifications right analysing the modifications of the resistance over time compared to the reference values can give some information about the variable gas concentration.

So, it is all written well here practical difficulty is what happens if the reference keep shifting and why should the reference shift? Yes, why not. The reference can shift if the pressure there is a variation atmospheric pressure variation if humidity changes, you can have change in base line shift if temperature changes temperature, pressure, humidity TPH as it is called TPH effect on the baseline is there significant not significant depends on manufacturer A, manufacturer B, C and so on.

But, you will have to take that into consideration and your fusion equation ultimately will have to factor in. How do you do that? Simple, have a TPH sensor along with existing air quality sensors. So, you know from manufacturers data sheet for this much temperature, this is the compensation that, you will have to provide and as per that you compensate it in your equation same for pressure, same for temperature, same for humidity.

Normally, I mentioned to you about dry gas in dry gas you will find that the baseline simply shifts because all. So, suppose you buy an NO 2 MiCS-4514 do a prototype design put it here and then you observe the some value that after tuning everything you take it inside a climate chamber there you and you live it inside that a climate chamber and pass dry gas in the dry gas there is only oxygen and nitrogen 78 and 22 percent you just add these two and then you are done and no humidity at all; dry gas, dry air baseline shifts right or you take it out it will come back and settle at some other value. So, it is a cat and mouse gaze. You will be just wondering what is actually happening when you are trying to do a calibration, ok.

Also therefore, while it is all written here beautifully you will have to consider these effects. So, the temperature pressure and humidity effects and therefore, you have to be careful about it. This is one part this is one part of the story. Second part of the story is you buy sensor a MiCS-4514 sensor A you buy sensor B. Sensor A and sensor B under same circuit conditions behave differently. How will you now worry about calibrating individual sensors that is not going to work out for you, right. Every single sensor you will have to calibrate. Somehow you have to come to some broad understanding of what the variation is right only then you can do something.

Therefore, they what they do is they typically take a ratio of the R s and the R naught; R naught typically is the baseline resistance that is available to you and that along with the change in resistance is taken and then you take a ratio of the two. So, you define a term called sensitivity which is defined by this ratio R s minus R naught divided by R naught you take that equation and keep that as your sensitivity parameter and then keep using that. So, that individual sensors need not be calibrated. That is the only way you can manage and come to something useful when you prototype across hundreds and thousands of sensors.

So, you see now why air quality has not taken off monitoring with IoT sensors these are some issues. Air quality you cannot afford to do a mistake right ppm to ppb if you do a mistake if it is your safe values or in ppb and you measure a make a measurement in ppm, it is gone, people are going to die. So, when it is life saving and all these critical things you are a system design should be perfect. Your system design should account for everything that manufacturers have found out in terms of problems.

Moment you do that you have additional components moment you have additional components those will have to be managed, power domains have to be managed, circuit becomes complex, circuit can fail because it can be it becomes complex, right. Then you have to have very intelligent software which detects the failure of a sensor and report senses whatever I am reading is incorrect because temperature sensor has failed or pressure sensor has failed or humidity sensor has failed and so on and so forth.

So, your software should be full of brains the designer who is designing the circuit should manage the power properly, he has to maintain certain voltage rails properly. Sometimes in a electrochemical applications the reference electrode has to maintain a constant voltage under any circumstance because it is the reference electrode and the electrode that you measure at the working electrode that actually tells you something about the concentration of the gas. And, therefore, you must maintain superly regulated voltage for these reference electrodes in the electrochemical some of the electrochemical system.

So, you read the data sheet, application note thoroughly before doing any system design I I do not have a magic formula for you and I have done this myself and therefore, confidently I can tell you that every single point has to be understood from a overall objective of what you are trying to do, ok. This is very very critical.

So, read this with lot of deeper understanding from what I said reference values is not so simple. We already discussed this, right.

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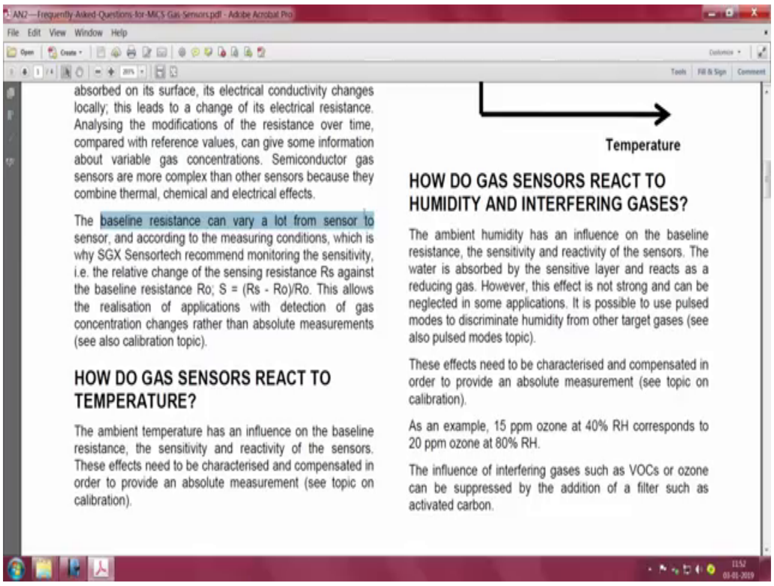

And, cross sensitivity is an issue. So, here you are the baseline resistance can vary a lot from sensor to sensor and according to measurement conditions which is why you talk about sensitivity and that is relative change of sensing resistance R s against the baseline resistance R o. This allows the realization of applications with detection of gas concentration changes rather than absolute measurements. How do gas sensors react to temperature? Yes, there is a problem, right.

You have to do compensation look here temperature sensitivity TPH temperature pressure humidity. How do gas sensors react to humidity? Yes, there is a problem, they are. Is it significant? Not significant is another issue look at this example 15 ppm measured at 40 percent RH corresponds to 20 ppm ozone at 80 percent RH. So, you have to compensate. So, the value you read off is dependent on what is the humidity level, RH level and therefore, this just an example. So, you have to ensure that this is also brought into the picture.

The influence of interfering gases that is cross sensitivity, VOCs. Well, that is another problem. So, you may have to do filtering right. You know RC filters very well which removes unwanted frequencies signal components quite like that when you want to remove a gas. You have to put a filter such as activated carbon is one such filter to remove certain VOCs that you do not want to interfere when you are making a measurement of only one type of gas, so, one type of target gas.

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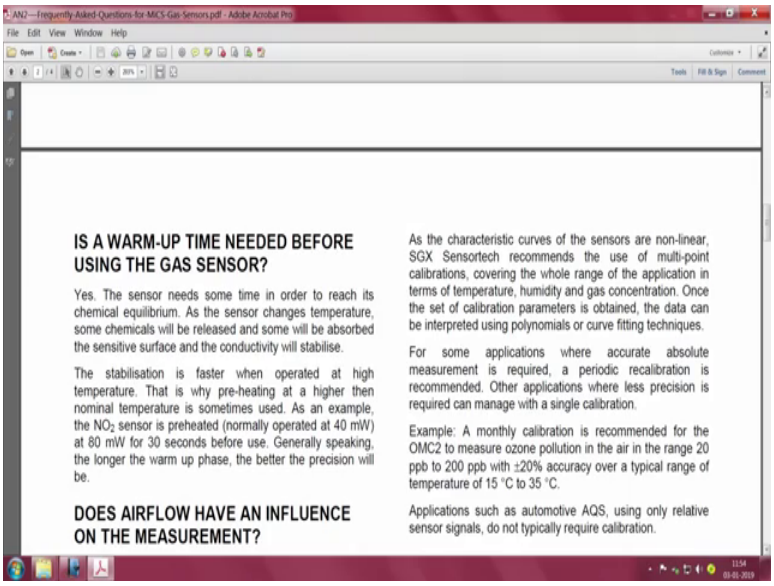

IS A WARM-UP TIME NEEDED BEFORE USING THE GAS SENSOR?

Yes. The sensor needs some time in order to reach its chemical equilibrium. As the sensor changes temperature, some chemicals will be released and some will be absorbed the sensitive surface and the conductivity will stabilise.

The stabilisation is faster when operated at high temperature. That is why pre-heating at a higher then nominal temperature is sometimes used. As an example, the NO_2 sensor is preheated (normally operated at 40 mW) at 80 mW for 30 seconds before use. Generally speaking, the longer the warm up phase, the better the precision will be.

DOES AIRFLOW HAVE AN INFLUENCE ON THE MEASUREMENT?

As the characteristic curves of the sensors are non-linear, SGX Sensortech recommends the use of multi-point calibrations, covering the whole range of the application in terms of temperature, humidity and gas concentration. Once the set of calibration parameters is obtained, the data can be interpreted using polynomials or curve fitting techniques.

For some applications where accurate absolute measurement is required, a periodic recalibration is recommended. Other applications where less precision is required can manage with a single calibration.

Example: A monthly calibration is recommended for the OMC2 to measure ozone pollution in the air in the range 20 ppb to 200 ppb with ±20% accuracy over a typical range of temperature of 15 °C to 35 °C.

Applications such as automotive AQS, using only relative sensor signals, do not typically require calibration.

Is warm up required? Yes, of course, I mentioned this to you already that unless you have a heater and you do some preheating and your measurements of NO 2 are not valid. So, people even suggests 6 hours of continuous heating from a off the shelf you buy, put it on board, you put it on for 6 hours, do not do nothing with it warms up completely then you are ready for making any measurements some people even suggest overnight heating; 12 hours of first time first time overnight heating and then repeat and subsequently no measurement is possible till the heater warms up to it is required condition.

Therefore, do not think of if you are supposing you are you are going to put this on a car and you are driving it out of a car battery moment you switch off the car ignition and everything comes down battery should still be connected to this board which essentially is housing all these pollution sensor and the heaters in them should be on. You may not do sensing, but you have to keep the heaters on, otherwise there is no way by which you can measure anything in real time.

What about the other problem of response right t 90 response? T 9 that is where you will pick your sensors of interest. Supposing there is a sensor which says t 90 response is 100 seconds. Well, in 100 seconds you would have gone if you are putting it on a vehicle 100 seconds you would have gone quite a distance, right. So, your measurement is incorrect you whatever you wanted to take a snapshot at one point is now completely in well by the time, ok.

Heater is still on you switch on and then make a measurement by the time in a moving vehicle by the time you would have crossed and the point at which it has sampled at whatever instant is incorrect because it has not gone to t of 90; t 90 comes 100 seconds later and that is another signal point which is less crowded perhaps or something else and then your measurement is totally incorrect.

I would choose that against some other sensor which gives you in 10 seconds. Even that is not a very effective if you are moving at very high speed you can do some calculations to find out at what distance you would have moved. If you let us say, travelling in a city, at I do not know may be 40 or 50 kilometre per hour and you would have gone 100 seconds and how much distance and where you would have all that you can do a calculations.

But, I am saying that you all this simply amounts to the fact that you will have to a know use that parameter also when you are trying to by your sensors again going back why air quality monitoring using IoT has really is a challenging problem is all because of these issues. So, I am just trying to sensitize you to these things. So, that is another thing, alright. So, there is a preheating thing not typically 40 milli volt.

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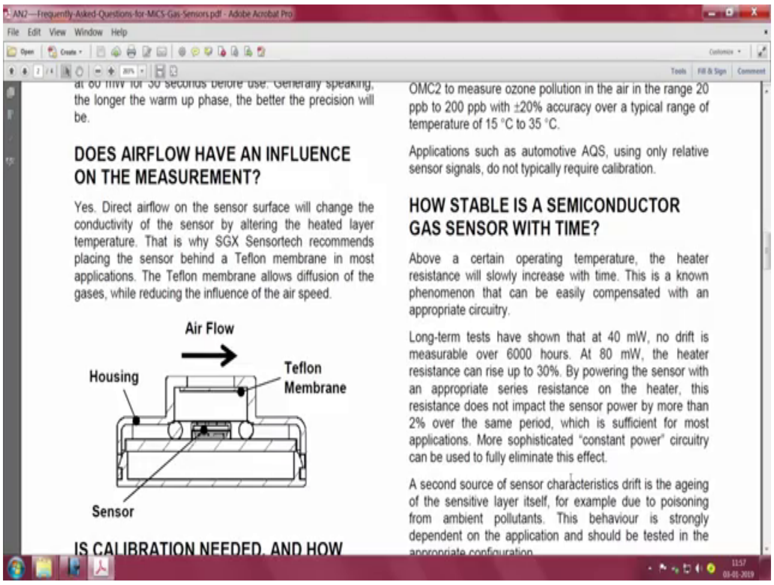

See this another thing airflow you cannot say I will buy this sensor and I will put it in the corner of some room or I will just leave it there and then let it measure the air quality, that is not going to work. You the sensor itself wants to see a flow either a laminar flow or a turbulent flow or whatever they do not specify that , but a flow is required; at what rate? What should be the flow rate? Is it 1 litre per minute? Is it 2 litres per minute? Is it 0.5 litres per minute? How much is? Is it 3 litres? What should be the flow? Right, in terms of volume because when you say litres and all that you talking about volume.

So, there is again lot of things people keep talking about and again from my experience I can tell you any flow in the range of 0.5 litres per minute to 1 litre per minute is considered to be good, ok. So, you will have to look at sucking the air using a pump or something and then allowing that pump to or bombard that air that you have sucked at a regulated rate of some point 5 or one litre per minute only then the measurement is right.

So, you see effects of TPH, effect of flow and other problem is poisoning; poisoning of the sensor means if it is going under you know lot of toxic materials come and bombarded the sensitive layer goes away, then it is then again you have a problem. So, you may have to apply several filtering mechanisms and we discussed that VOCs and all that means, you need that different type of filters and you know polluting gases is another issue. So, it is a very complex thing if you want to do a design of in air quality, you are keep this things in mind. So, that is another thing.

How often is calibration required? Well, you see this is another thing every vendors claims that if it a semiconductor sensor once you do a calibration you can be done with and all that. So, that is really not the case. The problem is that if you have a heater based system like the NO 2 the MiCS-4514 the heater it should be on continuously otherwise you cannot as I said make a measurement ; maybe in the night when you are switching of the complete car and it is, I mean I am assuming that all these sensors are mounted inside a car because it is doing a tail pipe monitoring as well as ambient monitoring, for both I am just assuming that you are making measurements as you go along in your path to your office or home or marketing or any mall or any shopping complexes and so on.

So, you just continuously you know gathering data because you have an IoT box which is now quite reasonably priced and very accurate dream, right you and then that is what you can put everywhere inside your homes inside, your cars, inside the bus where you sit for you travel or your train wherever you go and then you have to saying that here is a good quality air I am breathing this not so good, this not so good so on and so forth. Should not get paranoid about it, but at the same time you should be aware that sometimes it is not good for humans to breath some toxic gases, anyway that apart.

So, calibration is an issue and you can say roughly that one – two months irrespective whether it is electrochemical or the semiconductor you do not need to worry , but I think every 6 – 3 months or so you have to keep calibrating it baseline drifts will be there keep adjusting them and then move on from there. So, therefore, that is a really an issue.

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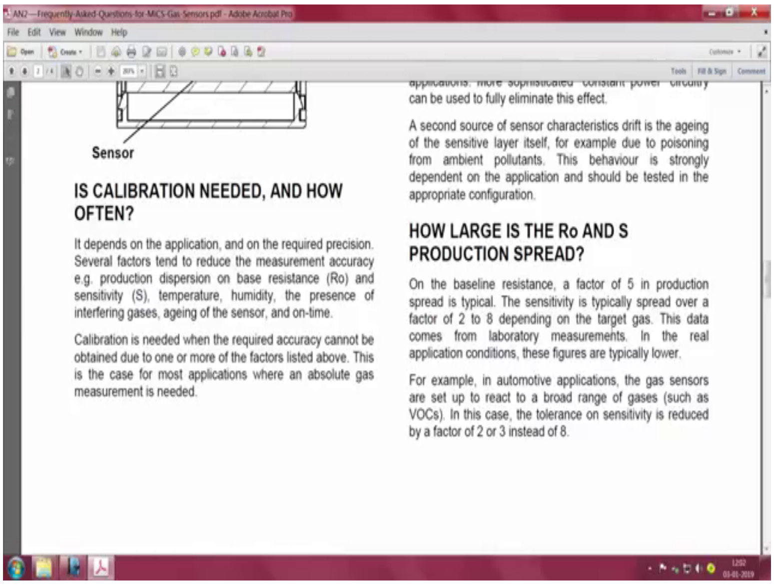

Then, how stable is the semiconductor gas sensor with time? Well, I did mention to you about the heaters problem. Once the heater comes down the system is not good enough for making a proper measurement because reactions do cannot take place as efficiently as they should at that given temperature. So, if you are heater is not functioning well reactions are not happening at all perhaps and therefore, your ability to detect a target gas also comes down. So, there are issues of that nature.

You have to though keep checking that and then accordingly adjust the current as an when the R values keep dropping, no if there is no drift ok. So, something like 6000 hours is and after that it will drop the heater resistance will increase. So, it will moment it increases heater resistance increases, the current drawn comes down and then the temperature it can attain is also reduced and therefore, you going have an impact, right; all these issues are there.

Now, what about these spread of R naught and s the current measurement under a target gas R naught as I said is that baseline value. A factor of 5 in production spread is typical the sensitivity is typically spread over a factor of 2 to 8 depending on the target gas. This data comes from lab measurements and all that. For example, in automotive applications the gas sensors are said to react to a broad range of gases in this case the tolerance of sensitivity is reduced by a factor of 2 or 3 instead of 8. So, you will have to look at this also as an important parameter, alright.

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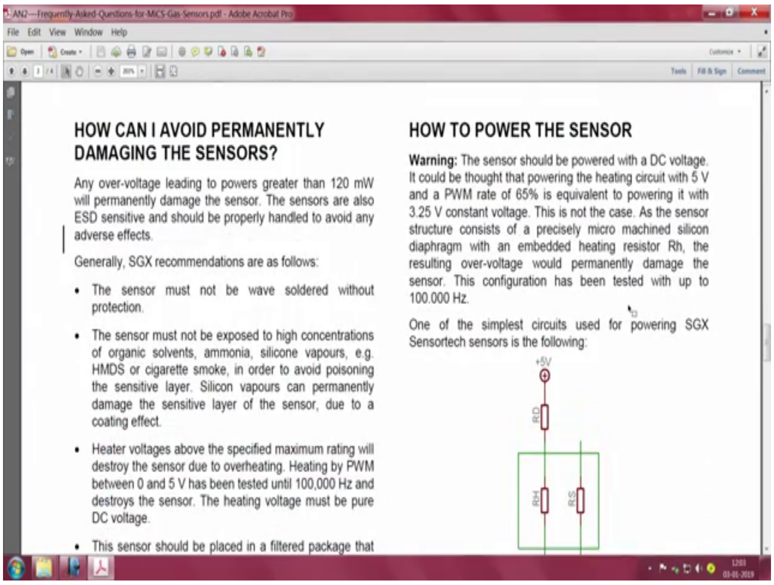

How to avoid permanent damage to sensors? Well, you have to be take care of over voltage, you have to take care of ESD and you should do only wave soldering of this sensor on the board.

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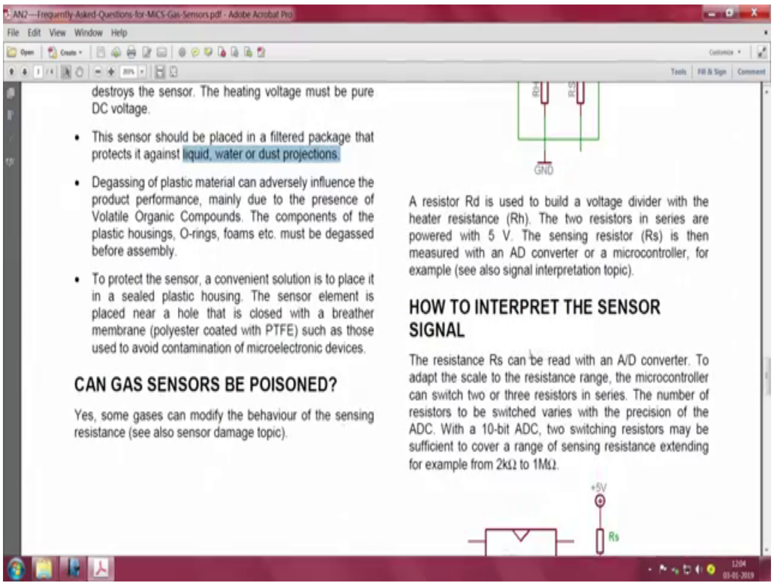

You should not be exposed to high concentrations of any organic solvents. Heater voltages should be well within the range you should not apply DC – DC converter output for heating voltage. It should not be a switched power supply output rather it should be a DC clean DC voltage that is being applied to this heaters. The sensor should be packed so that it is filtered against liquid, water and dust projections. Degassing is another problem of plastic material. So, you have to avoid presence of VOC compounds, ok, all that is a very important thing. Can they be poisoned? Yes, sure they can be poisoned. So, you, as I mentioned to you, that you have to take care of this poisoning.

So, this part of the circuit here you can see, this part here is essentially heater. So, do not break your head so much about it. R h, R d, this 5 volts to ground heater is there; R s is what of is of is your interest, R naught is the baseline resistance value, R s is the value of resistance that you measure due to target gas and that is what he mentions here that this what you want to actually measure. Over voltages have to be ensured that you do not apply higher voltages and no switching voltages, that also mentioned there.

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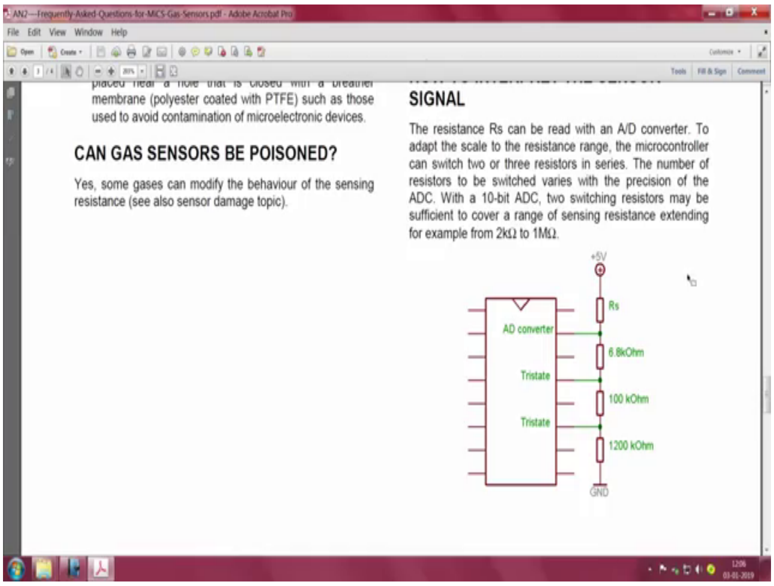

Now, R s is what you get and that you can give it to an ADC, and you could essentially apply a bank of resistors for your resolution requirements, ok. You can have this kind of a range of values 2 k to 1 meg for you to get a different steps when you do your ADC measurements depends. So, therefore, mostly on your resolution that you want to measure you have.

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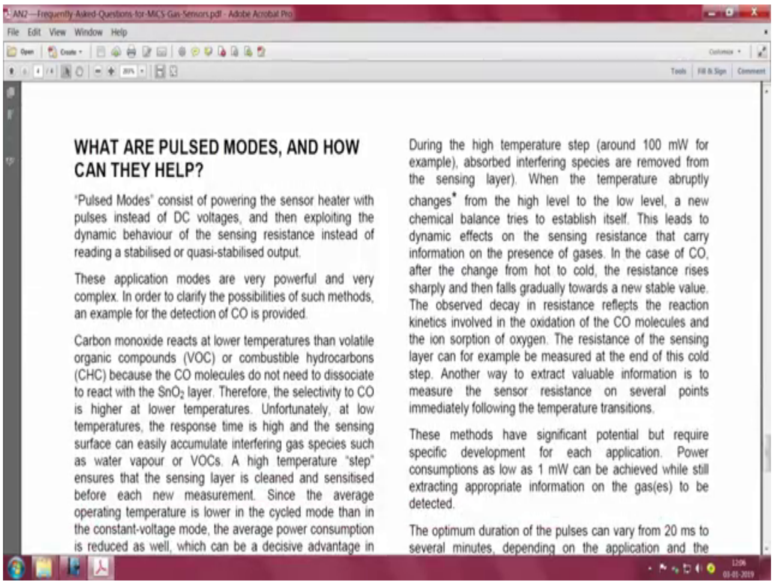
WHAT ARE PULSED MODES, AND HOW CAN THEY HELP?

"Pulsed Modes" consist of powering the sensor heater with pulses instead of DC voltages, and then exploiting the dynamic behaviour of the sensing resistance instead of reading a stabilised or quasi-stabilised output.

These application modes are very powerful and very complex. In order to clarify the possibilities of such methods, an example for the detection of CO is provided.

Carbon monoxide reacts at lower temperatures than volatile organic compounds (VOC) or combustible hydrocarbons (CHC) because the CO molecules do not need to dissociate to react with the SnO_2 layer. Therefore, the selectivity to CO is higher at lower temperatures. Unfortunately, at low temperatures, the response time is high and the sensing surface can easily accumulate interfering gas species such as water vapour or VOCs. A high temperature "step" ensures that the sensing layer is cleaned and sensitised before each new measurement. Since the average operating temperature is lower in the cycled mode than in the constant-voltage mode, the average power consumption is reduced as well, which can be a decisive advantage in

During the high temperature step (around 100 mW for example), absorbed interfering species are removed from the sensing layer). When the temperature abruptly changes* from the high level to the low level, a new chemical balance tries to establish itself. This leads to dynamic effects on the sensing resistance that carry information on the presence of gases. In the case of CO, after the change from hot to cold, the resistance rises sharply and then falls gradually towards a new stable value. The observed decay in resistance reflects the reaction kinetics involved in the oxidation of the CO molecules and the ion sorption of oxygen. The resistance of the sensing layer can for example be measured at the end of this cold step. Another way to extract valuable information is to measure the sensor resistance on several points immediately following the temperature transitions.

These methods have significant potential but require specific development for each application. Power consumptions as low as 1 mW can be achieved while still extracting appropriate information on the gas(es) to be detected.

The optimum duration of the pulses can vary from 20 ms to several minutes, depending on the application and the

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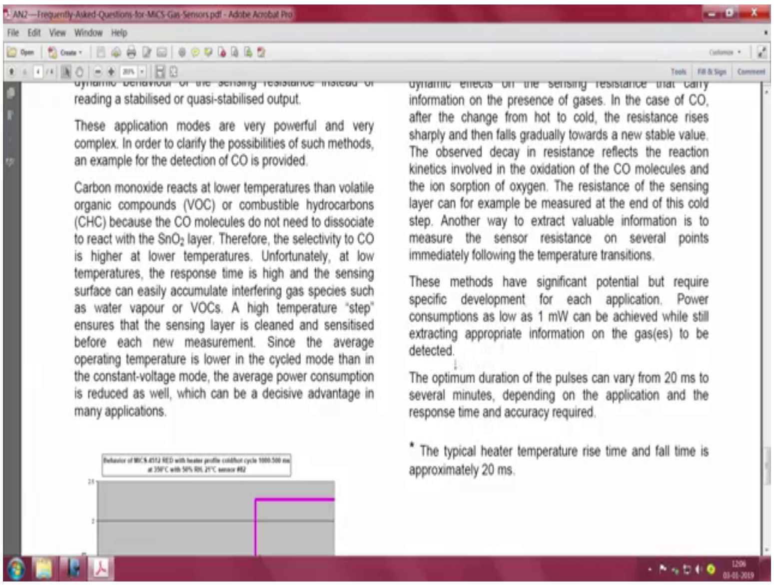
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* The typical heater temperature rise time and fall time is approximately 20 ms.

So, this is discussion on whether in order to save energy can we do pulse power and this discussion essentially is about that.

Thank you very much.