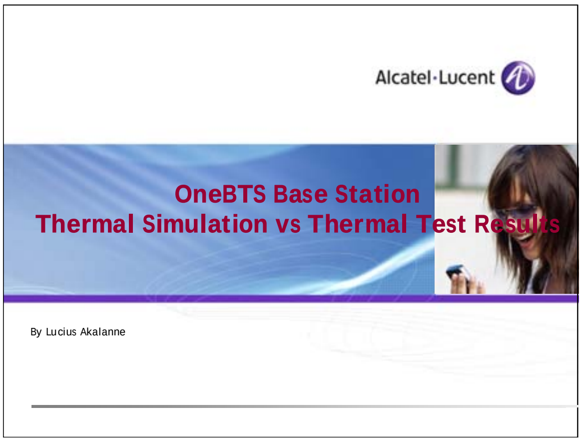
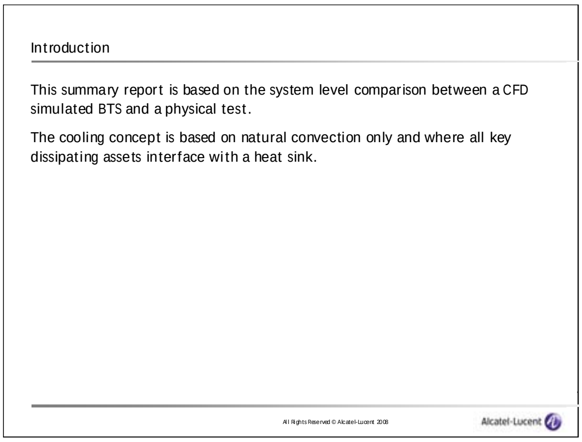
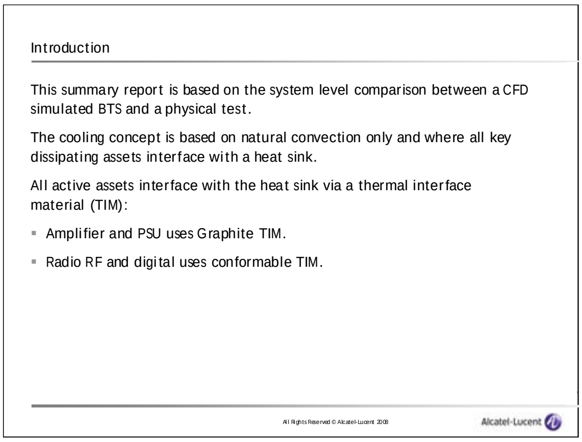
Thermal Simulation vs Thermal Test Results



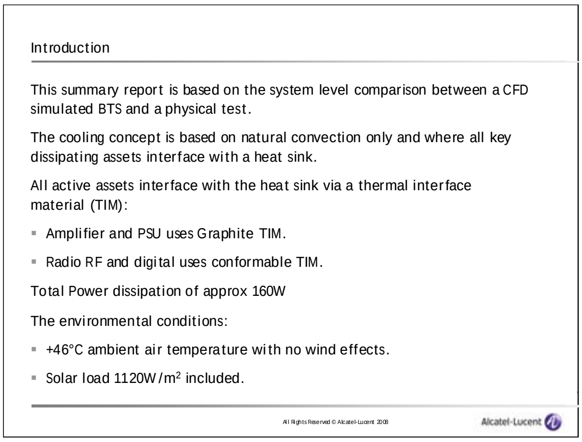
The presentation today is going to be based on a natural convection case. Natural convection cases are one of the most difficult problems to solve. You can classify it as a static system, unlike forced convection systems, because with forced convection systems, typically, if you do have problems during the testing phase, you can increase your fan speed. Of course you will have acoustic issues, but then there are other solutions: you can dampen your enclosure to try and dampen out the noise. Whereas with natural convection there is no way of increasing the fan speed: the design is set, the enclosure size is set, and the number of parameters that you can vary to try and enhance heat transfer is dramatically reduced. So it’s very important and it’s very critical during natural convection to ensure that you have all the correct parameters and due diligence.



This presentation, like I said, it’s really a comparison between the natural convection simulation case that was done early on during the cycle of the project compared to a thermal test that was done latterly during the design cycle, so the solution is a natural convection solution. In the solution, we have different assets: we have an amplifier, a radio, an optical card which has very little power, an RF filter, which filters RF. The key things really are the amplifier and the radio,

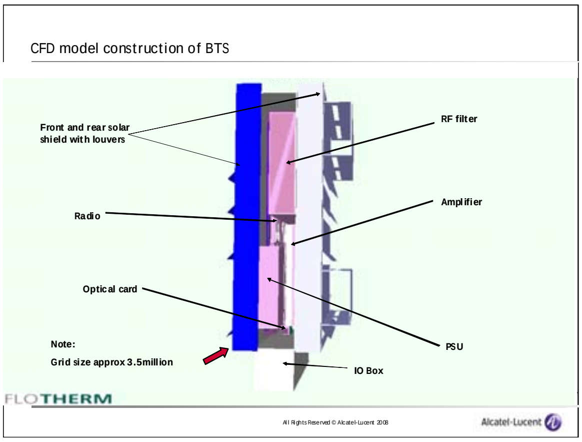


The amplifier interfaces with the heat sink with a graphite material. Graphite is used because it has very good grounding properties and also it’s a fairly good thermal conductor. On the radio, we use a conformable-type material. One of the properties of that is that it’s a very good insulator, so you want to ensure the characteristics of the performance of your radio is not affected by interfacing with the heat sink. You really want to isolate your radio and ensure that each part of the radio design is controllable.

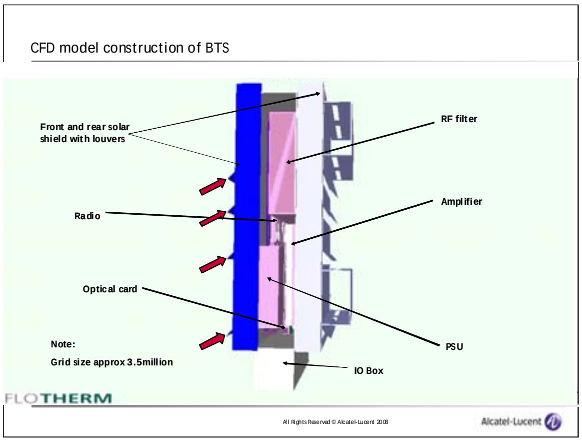


The total power of the unit is about 160W, that is the total power. The power has gone up since this design, but this case is basically 160W and that splits between the different assets internally. The environment that we’re considering here was 46°C ambient with no wind effects and estimated solar load of 1,120W per metre squared. During the design cycle the external ambient temperature changed for the design from 46°C to +50°C, so you will see some slides saying 46°C but everything has been referenced off the same temperature of +50°C.

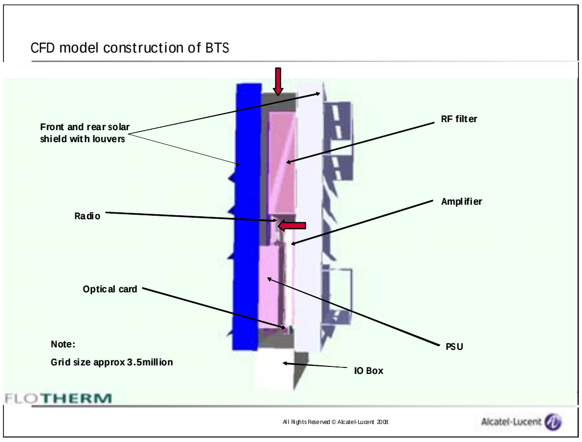
Thermal Simulation vs Thermal Test Results



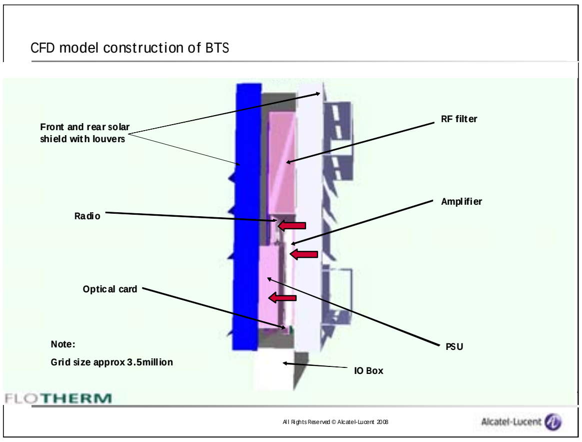
This shows the construction of the model. On the left-hand side you can see a blue cuboid. That's the front solar shield that protects the unit, the idea behind that is obviously to minimise the solar gain to the enclosure.



On that solar shield you can see some angles jutting out from the surface and those are louvers. The idea of the louvers is that it enables entrained air to enter the fins at different points, so you provide cooling at different points to the sink. Rather than preheating the air at the bottom and continuously preheating it until it exits at the top. The other benefit of the louvers is that not only does it allow cool air to enter, it also deflects the solar load from migrating to the heating surface.

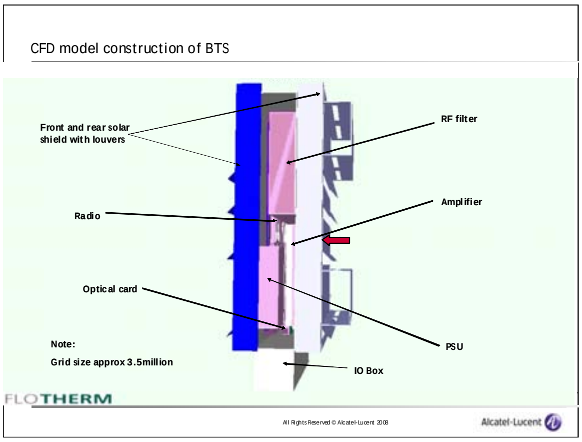


Behind the blue cuboid is basically a heat sink that has an array of fins on it. Then we move to the internal part of the enclosure, we have a radio, so if you have a look at the radio, the radio is on the same surface as the power supply unit, the power supply is a unit that supplies power to the different assets inside, so provides power to the radio, to the amplifier, and every other thing inside the enclosure.

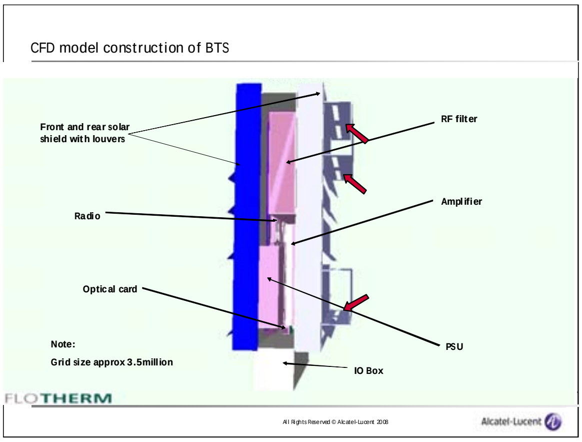


Each of these units, it's important to be aware, they have their individual efficiencies, and devices have their efficiencies, and the assets, like the amplifier, has its efficiency, the power supplier has its efficiency and so does the radio. The radio and PSU, which is the power supply unit, interface on one side, so there's thermal coupling between these two units, so that's one part of the problem. On the opposite surface we have an amplifier, which interfaces, like I said, with graphite to the heat sink and that's really isolated by itself, there's little firm interaction between the amplifier and the power supply and radio.

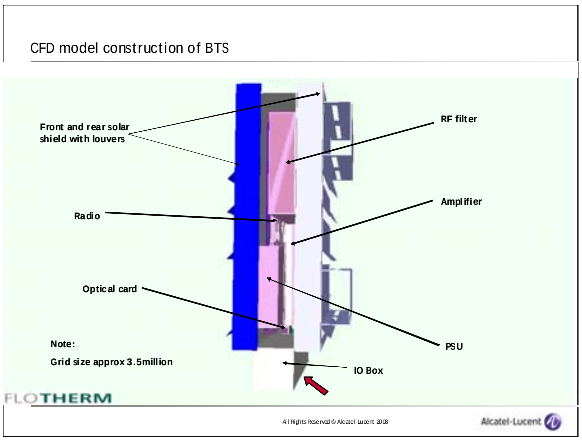
Thermal Simulation vs Thermal Test Results



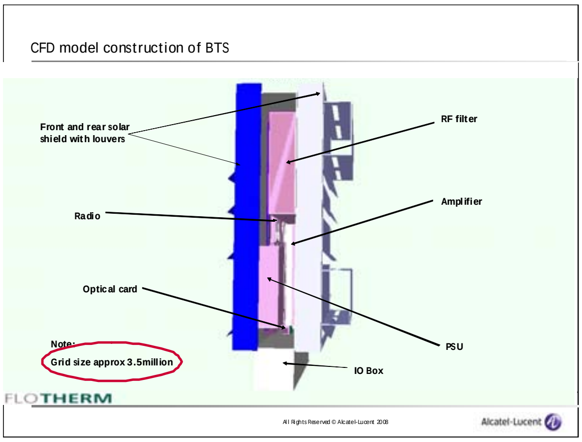
Moving across to the right, again we can see similar geometry to that on the left but this time it's grey and again that's another solar shield with louvers, that does exactly the same thing as I said before, deflecting solar, allowing cool air to enter at different points, but additionally what you can find here is a rear mounting bracket, because the unit is designed to be mounted on different surfaces.



So the solar shield on the back is to protect it. If you were mounting up a pole, then obviously you can't guarantee where the solar is going to be, so it gets protection from that surface. When it's mounted on a wall that's different, you'll be protected by the wall, so you don't really need the solar shield, so the solar shield is integrated into the wall mounting bracket. On the wall mounting bracket you can see additional cut-outs, and the idea of the cut-out is to ensure that you don't have trapped heat within each of those tubes, so with solar migrating to this side of the tubes the heat can evacuate and natural convection can remove the heat.

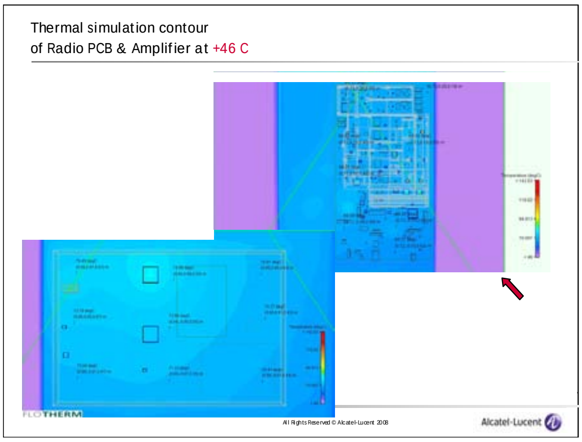


On the bottom of the unit there's an input/output box, which is where you have all the cables coming in, alarms, etc. Again, it's been designed to ensure that you don't block the air flow to the fins and again, the fins are behind the blue and grey bits.

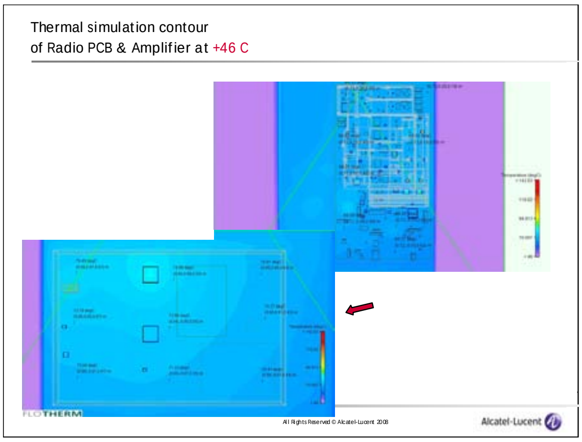


The grid density, just to tell you a bit more about the model, the grid density on this model is 3.5 million grid. The grid is this dense to be able to capture both the components and both the system level model, so you have all the devices mounted on the radio, which have been captured here, you have all the devices mounted on the amplifier, again, that has been captured here, and the grid has been constrained so that it doesn't bleed to other areas, to try and minimise the grid size but to still capture all the details inside the model.

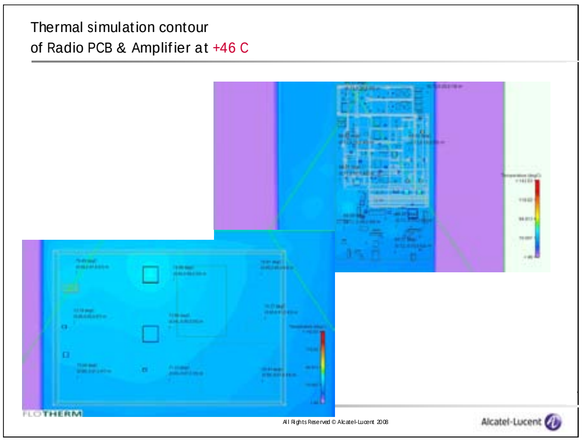
Thermal Simulation vs Thermal Test Results



Here you can see a section view of the thermal plot over the radio and over the amplifier, as mentioned before. On the radio we're monitoring over a hundred devices. When I say we're monitoring, we're ensuring that approximately a hundred devices, the majority, the key devices, don't exceed their maximum allowable junction temperature. So there's an awful lot of detail, there's an awful lot to watch ensuring that you're still within the design spec.

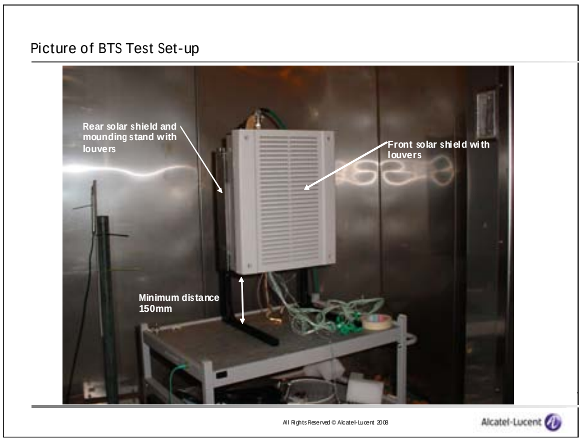


On the amplifier, the left device is not as dense but again there's a similar problem: you have to ensure that the devices don't exceed their maximum junction temperature. So you have to look for things like coupling between devices, ensuring a device is sufficiently distanced to reduce thermal coupling. That's the problem from the board-level perspective.

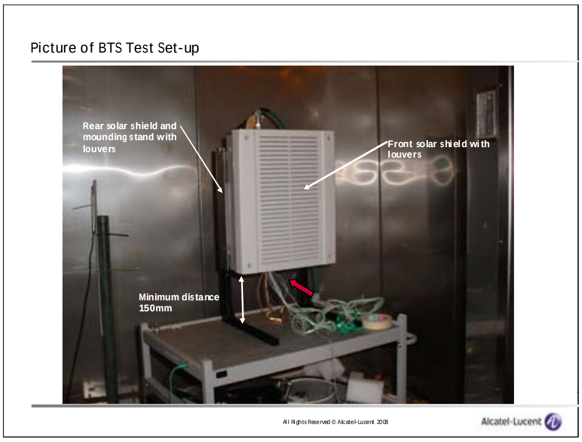


At this stage, this is the very early development stage of the design programme, and what this enables you to do, it enables you to be able to design your module, it enables you to be able to perform reliability assessments on your system, so you can assess your reliability, you can understand how reliable your product is, and maybe you have to go back and redesign to make sure it's a bit more reliable. It allows you to be able to do weight analysis on your enclosure at the early development cycle, you know roughly how much your enclosure is going to weigh, you can do cost analysis, you can do cost reduction. All this is really at the early development cycle, so these are the other benefits of performing thermal simulation very early on at this stage, so you have a certain amount of confidence that you're not penalising the thermal solution, because you understand the constraints, you understand the limits, and you're working within the environmental requirements, such as temperature, altitude, solar, etc.

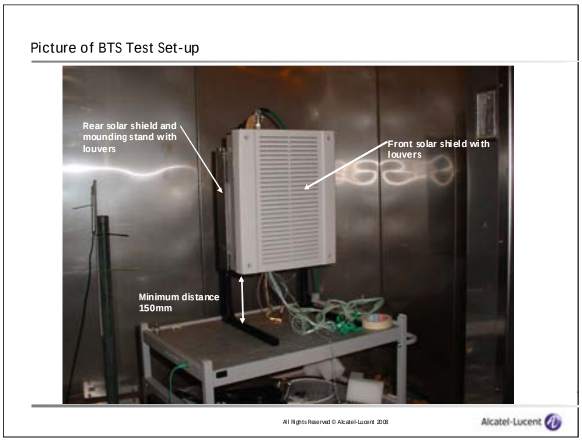
Thermal Simulation vs Thermal Test Results



I'll move on to the next slide, where we go on to the set-up. The simulation has been done, we understand all the parameters, we understand the limits, and then further on during the design cycle you reach the stage where, when you start testing, you start having units coming in and you build your model with the amplifier radio power supply and you have your heat sink, you interface everything together. It's very important that at this stage you closely monitor the build of your test module, because things that are very critical are interfaces, making sure everything interfaces properly, you have the right torque, you have the right pressures that you're expecting, you have the right contact resistance, to make sure that there's no gaps between devices to be cooled and the cooling source, for example, so all those things are very important to verify during your stage.

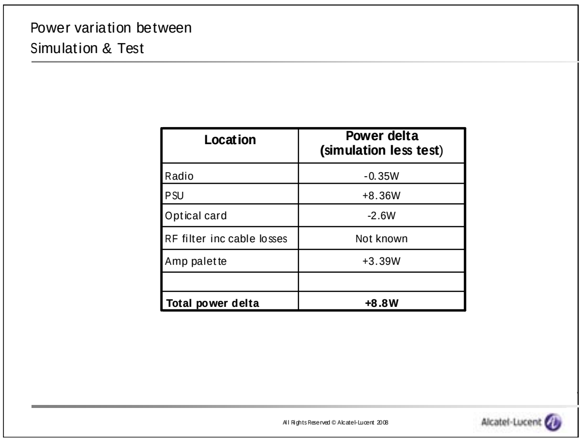


Here at the bottom of the picture you can see thermocouples coming out of the unit, and these thermocouples are interfacing with all the key devices on the radio and key devices on the amplifier, as well as other key areas within the units, like the RF, air temperature, and other devices which are equally as important but perhaps not as high priority as the radio and amplifier.



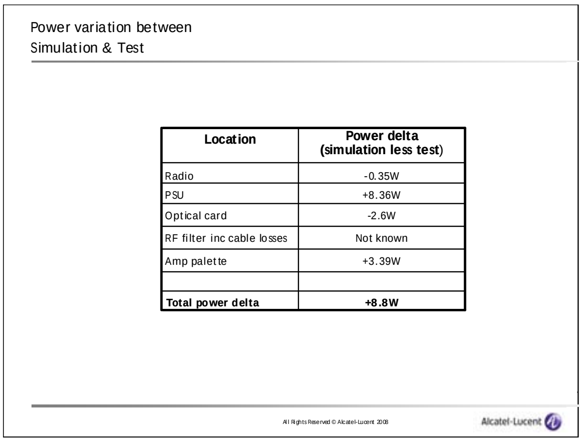
The natural convection cool unit you can see here is inside a chamber. The reason it's placed inside a chamber is to ensure you don't have air conditioning issues. If you were to test it in a lab you could have air conditioning issues with oscillating air conditioners, etc., people walking past, and that would affect the test results because instead of reaching a steady state it's still in a dynamic state. So the unit was placed inside a chamber to ensure that you had eliminated all those type of variables. The chamber, again, in this case, was at ambient temperature, so you don't have fan effect, the chamber fan effect affecting your test. Natural convection is obviously very low velocity. Switching on your chamber will affect your results because you're basically introducing forced convection, unless your unit is very well protected and baffled away from the fans. The steady state took about three hours for this unit and the temperature was monitored with a data logger, and after steady state some of the results were taken and then compared.

Thermal Simulation vs Thermal Test Results


Power variation between
Simulation & Test

Location	Power delta (simulation less test)
Radio	-0.35W
PSU	+8.36W
Optical card	-2.6W
RF filter inc cable losses	Not known
Amp palette	+3.39W
Total power delta	**+8.8W**

Here you can see a comparison between the power differences between the simulation and the test. The difference between the radio simulation and test, the radio was 0.35W less during the test. Power supply was 8W more power during the test; optical card had less power by 2.26. The RF filter and cable losses are very difficult to measure, they're fairly negligible when compared to the total power, so the amount of effort to try and measure those is just not worth it, it's negligible power. Amplifier was 3.39W higher. These are differences in power dissipation between the simulation and test. Then you end up with a total power delta of plus 8W, so the unit, on doing the test, was dissipating 8W more power.


Power variation between
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RF filter inc cable losses	Not known
Amp palette	+3.39W
Total power delta	**+8.8W**

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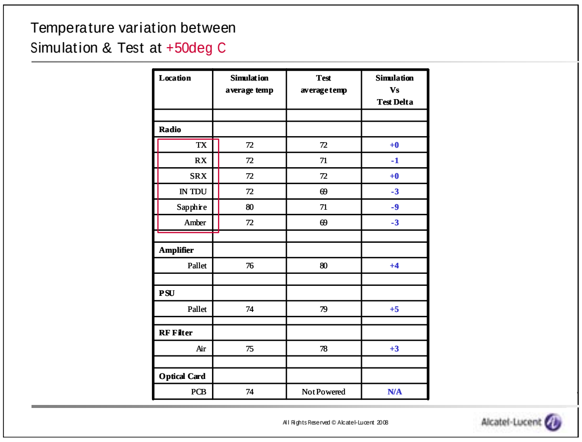
At this stage, when you're looking at your power both during the simulation and the test, it's extremely important that you liaise very closely with the RF designers to understand the power dissipations of not only the devices of the circuit pack. Again for the amplifier you need to work closely with the digital designers to understand the power dissipations of all the digital assets. You need to work, clearly, with the power architect, so that you can understand the different efficiencies of different units and how the architecture of the power goes together and that could affect the power dissipations of the different units. You also need to work closely with the system architect to understand how the unit is going to be put together, because a situation that may be ideal from the thermal perspective may not be ideal from the system architecture perspective, for example, the power supply being on the same side as the radio is perhaps not the ideal way of doing it thermally but system-wise it makes a whole lot of sense because you shorten your cable length and reduce losses, etc. So you need to work closely with all these different key skills to make sure that the data you're using is correct and also your understanding is correct.


Temperature variation between
Simulation & Test at +50deg C

Location	Simulation average temp	Test average temp	Simulation Vs Test Delta
Radio			
TX	72	72	+0
RX	72	71	-1
SRX	72	72	+0
IN TDU	72	69	-3
Sapphire	80	71	-9
Amber	72	69	-3
Amplifier			
Pallet	76	80	+4
PSU			
Pallet	74	79	+5
RF Filter			
Air	75	78	+3
Optical Card			
PCB	74	Not Powered	N/A

Here we're showing the temperature deltas between the simulation and tests. On the radio we have the different sections, TX is basically transmit and receive section, synthesiser section, and two devices, Sapphire and Amber devices, which are digital devices, two key devices. This is just a small summary of what was monitored on the radio. Like I said, it's over a hundred devices, and that would include another slide presentation which I could then do.

Thermal Simulation vs Thermal Test Results

Temperature variation between
Simulation & Test at +50deg C

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Radio			
TX	72	72	+0
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Amplifier			
Pallet	76	80	+4
PSU			
Pallet	74	79	+5
RF Filter			
Air	75	78	+3
Optical Card			
PCB	74	Not Powered	N/A

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You can see the temperature deltas between simulation and test on the fourth column, 0°C between the TX, minus 1, so the RX was 1 degree cooler in test, Sapphire was 9°C cooler and Amber was 3°C cooler. All that's on the radio.

Temperature variation between
Simulation & Test at +50deg C

Location	Simulation average temp	Test average temp	Simulation Vs Test Delta
Radio			
TX	72	72	+0
RX	72	71	-1
SRX	72	72	+0
IN TDU	72	69	-3
Sapphire	80	71	-9
Amber	72	69	-3
Amplifier			
Pallet	76	80	+4
PSU			
Pallet	74	79	+5
RF Filter			
Air	75	78	+3
Optical Card			
PCB	74	Not Powered	N/A

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Then you move on to the amplifier, you can see the amplifier was 4°C warmer, the power supply was 5°C warmer during the test than simulation. RF filter was 3°C warmer. RF filter is really suspended in here and is reliant on the power dissipations of the assets warming the internal air. Optical card, that was not really powered so we didn't really monitor that.

Temperature variation between
Simulation & Test at +50deg C

Location	Simulation average temp	Test average temp	Simulation Vs Test Delta
Radio			
TX	72	72	+0
RX	72	71	-1
SRX	72	72	+0
IN TDU	72	69	-3
Sapphire	80	71	-9
Amber	72	69	-3
Amplifier			
Pallet	76	80	+4
PSU			
Pallet	74	79	+5
RF Filter			
Air	75	78	+3
Optical Card			
PCB	74	Not Powered	N/A

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Again, if you look closely at what's high in temperature, the amplifier and power supplier are high in temperature, and if we go back to the others, the previous slide, you can see that the power supply went up in power by 8W and the amplifier went up in power by 3W, perhaps not surprising but those are the deltas.

Summary of Study – 1

In summary the Simulation vs Test comparison shows the average temperature delta as follows:

- Radio test on average 4°C cooler.
- Amplifier, PSU and RF Filter on average 4°C warmer.

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The final slide is just a summary of what I've mentioned so far. The radio was 4°C cooler, amplifier, power supply and (*AUDIO) filter were roughly 4°C warmer.

Thermal Simulation vs Thermal Test Results

Summary of Study – 1 In summary the Simulation vs Test comparison shows the average temperature delta as follows: ▪ Radio test on average 4°C cooler. ▪ Amplifier, PSU and RF Filter on average 4°C warmer. Simulation analysis (Flotherm) benefits (key points): ▪ Aided evolution of asset designs and dissipation power during the design feasibility cycle. • Allowed early reliability calculations and life estimates to be predicted. All Rights Reserved © Alcatel-Lucent 2008 Alcatel-Lucent	Performance simulation analysis added several benefits that I've mentioned and some key points I've mentioned here: it aided evolution of the asset design and dissipation power during the design feasibility stage. So basically the design was able to evolve. We had a look at variation of power dissipations during the asset, during the early development cycle, and were able to be sure that, with all these changes in evolution, we were still within the maximum allowable temperatures and the penalty to reliability wasn't drastic, and if it was, then we had to go back and redesign.
Summary of Study – 1 In summary the Simulation vs Test comparison shows the average temperature delta as follows: ▪ Radio test on average 4°C cooler. ▪ Amplifier, PSU and RF Filter on average 4°C warmer. Simulation analysis (Flotherm) benefits (key points): ▪ Aided evolution of asset designs and dissipation power during the design feasibility cycle. • Allowed early reliability calculations and life estimates to be predicted. ▪ Provided an understanding of the cooling capacity and limits of the enclosure before first build of prototype and test. • Provided accurate temperature prediction in the early development cycle of the product. All Rights Reserved © Alcatel-Lucent 2008 Alcatel-Lucent	The other benefits during the simulation stage: it provided an understanding of the cooling capacity and limits of the enclosure before the prototypes are built, before physical testing was done and before metal was cut. It provided accurate temperature prediction in the early stage of the development cycle, as was said, plus or minus 4°C is the temperature deltas that we've seen.
Summary of Study – 1 In summary the Simulation vs Test comparison shows the average temperature delta as follows: ▪ Radio test on average 4°C cooler. ▪ Amplifier, PSU and RF Filter on average 4°C warmer. Simulation analysis (Flotherm) benefits (key points): ▪ Aided evolution of asset designs and dissipation power during the design feasibility cycle. • Allowed early reliability calculations and life estimates to be predicted. ▪ Provided an understanding of the cooling capacity and limits of the enclosure before first build of prototype and test. • Provided accurate temperature prediction in the early development cycle of the product. All Rights Reserved © Alcatel-Lucent 2008 Alcatel-Lucent	It's very important, I'd just like to reiterate, that the thermal designers liaise very closely with all the other key skills, so obviously mechanical engineers, mechanical RF, digital architectures, etc. It's also extremely important that you understand the powers that are being used, how they're being used for the different assets, for the different devices, understand all the thermal resistances for the different components, understand how the unit is physically put together, ensuring that pressures are correct, interfaces, etc., because all this affects your result in the end.
Summary of Study – 2 Managing and understanding Simulation vs Test discrepancies (few pointers): ▪ Liaison with all internal and external functional teams is key to data control and model build accuracy. • i.e. do all the material data used reflect expectation? All Rights Reserved © Alcatel-Lucent 2008 Alcatel-Lucent	The final point is the managing and understanding simulation versus test discrepancies. Just a few pointers. Liaise with all internal and external functional teams is key to data control and model accuracy. Do all material data used reflect expectation? So everything that you're using, does that match what you're expecting, for example, are you using a machine heat sink rather than a cast heat sink to do your test? You need to understand that, you need to factor that into your result.

Summary of Study – 2 Managing and understanding Simulation vs Test discrepancies (few pointers): ▪ Liaison with all internal and external functional teams is key to data control and model build accuracy. • i.e. do all the material data used reflect expectation? ▪ Mechanical verification of test model should always be conducted. • i.e. have all assets being fitted with the right pressures? All Rights Reserved © Alcatel-Lucent 2008 Alcatel-Lucent	Mechanical verification of test model should always be conducted, so right pressures, check interfaces. One of the situations that happened was that one of the digital devices was I think about 20 or 30°C warmer than predicted and we couldn't understand why. We cracked open the unit, took a look and we discovered that the device wasn't contacting the thermal interfacing material, so we did it up to the right pressure, the right torque, put the unit back together, retested, and it was about 4°, I think 4°C cooler. It's very important that you check any discrepancies.
Summary of Study – 2 Managing and understanding Simulation vs Test discrepancies (few pointers): ▪ Liaison with all internal and external functional teams is key to data control and model build accuracy. • i.e. do all the material data used reflect expectation? ▪ Mechanical verification of test model should always be conducted. • i.e. have all assets being fitted with the right pressures? ▪ Verification of asset power dissipations where ever possible should be carried out. • i.e. are power dissipations aligned between simulation and test? All Rights Reserved © Alcatel-Lucent 2008 Alcatel-Lucent	Other things that can happen is that perhaps devices are dissipating a lot more power than expected or electrically predicted, so the more devices that you can measure from the power perspective to verify the powers that you're using, is also key. During this programme, all the devices were electrically verified to ensure that they were dissipating the right power, so we had very good confidence of the powers that we were using for the thermal simulation and we were using for the thermal test.
Summary of Study – 2 Managing and understanding Simulation vs Test discrepancies (few pointers): ▪ Liaison with all internal and external functional teams is key to data control and model build accuracy. • i.e. do all the material data used reflect expectation? ▪ Mechanical verification of test model should always be conducted. • i.e. have all assets being fitted with the right pressures? ▪ Verification of asset power dissipations where ever possible should be carried out. • i.e. are power dissipations aligned between simulation and test? ▪ Ensure test environment is fit for purpose. • i.e. is chamber fan speed suitable for natural convection cooling? All Rights Reserved © Alcatel-Lucent 2008 Alcatel-Lucent	Then the last point: ensure test environment is fit for purpose. Like I was saying before, this is a natural convection case, it's very critical, very sensitive. You have to ensure that you don't put it in environments that could be easily influenced and affect your results, so just ensure that your environment is fit for purpose.