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Technical Note TN0004

600 Bar Upgrade for Alliance 2695 Systems

Titel
600 Bar Upgrade for Alliance 2695 Systems

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Version
1.03

Updated
21.06.2010

Instruments
Waters Alliance 2690/95

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1 Introduction

We like to introduce our new Alliance 2695 high pressure Upgrade. The idea is to enable the use of Rapid Resolution, U-HPLC, or other columns with >2µm particles for Alliance 2695 systems. Because of the column technology the runtimes are reduced, resolution and sensitivity increased. The disadvantage of these columns are that they require higher pressures and the Alliance reaches its pressure limit. With the upgrade installed, the customer has a larger available pressure range. The upgrade was introduced to the public the first time at the Analytica 2010 in Munich-Germany. We have shown a live demo of an upgraded system running over 600bar.

2 Why is it possible to run higher pressures?

One answer for this question might be found when you ask vice versa, why is the pressure in the Alliance limited? The answer is, that by the time, when the Alliance was introduced the sub two micron column technology was under development and there was no need to run ultra high pressures. A second consideration is, that the Rheodyne valves for the column oven or the inject valve in the Alliance 2790 were rated to 5000psi (345 bar). For that reason the pressure is limited to that point by the software, but you can run up to 5500psi (380bar) when the Alliance is offline and controlled via the keypad. The third reason is the marketing strategy of Waters. For them it is not beneficial to have a competitive product besides their premium line.

When the Alliance system was introduced, Waters gave 5 years warranty on the pump drive assembly (customers call it torpedo). That was not only a marketing gag, the developers of the Alliance were convinced that they built a highly rugged pump. Warranty time was reduced later, because the early series started to leak oil through the seals. The new type of linear drives were lubricated with lithium grease for lifetime.

When the Alliance was released, a similar technology was only used by Ranin/Varian in their SD1 pumps (Fig.1).

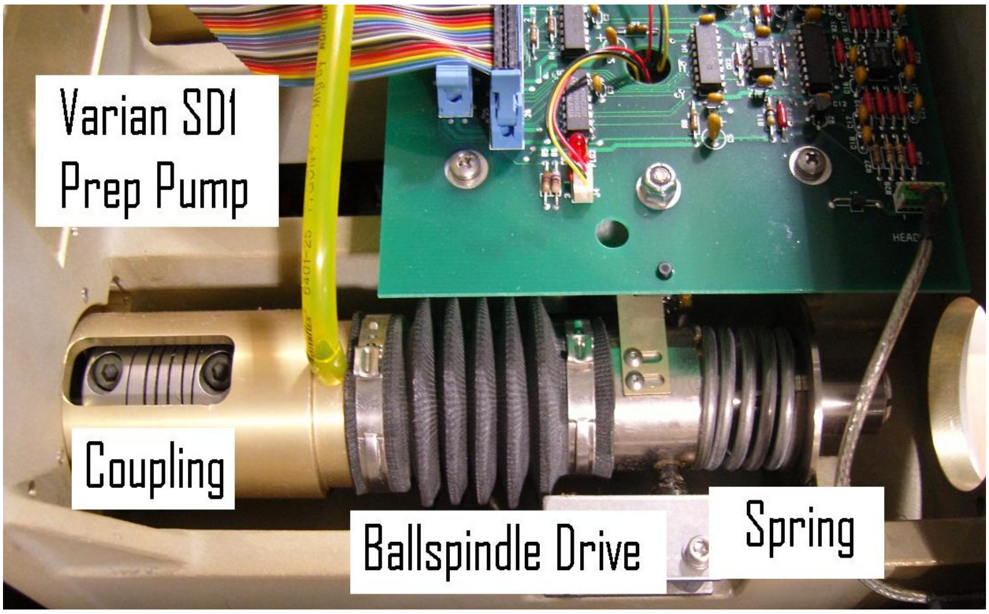

Figure 1: Linear motion drive of a Varian SD1 Prep Pump

Compared to other instrument manufacturers the Alliance linear drive is kind of special and many ideas from that product are now used in the Acquity system. The Alliance pump technology uses a linear motion spindle drive. Because of that, the stroke volume is variable and due to separate pressure sensors and an intelligent motion control, the pump flow is stabilized. This principle is part of the new UPLC H-Class concept as well as in the Agilent 1290. This technology is standard in CNC metal working machines. It is used to move a slit where the workpart is mounted on. These machines work precisely within a thousand of a millimeter and can apply large forces.

The heart of the Alliance pump is a linear motion drive. A screw, driven by a motor, rotates and the nut moves down the shaft. As the screw turns, the nut moves forward or backward on the shaft, the balls inside also move and must be recirculated. The ball recirculation is accomplished either externally, via a return tube (Fig.3, 5), or internally via ball deflectors that guide the balls over the thread (Fig.7).

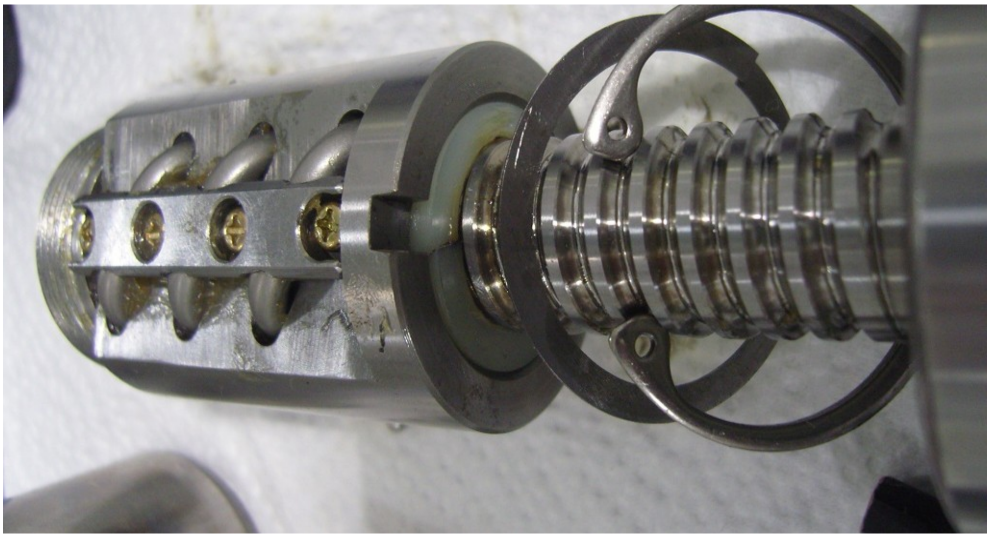

Figure 2: Lead screw with ball return tubes, Waters 25X5

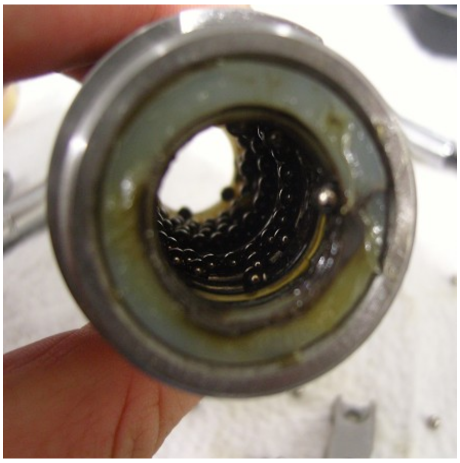

Figure 3: Plenty of tiny little balls...

Figure 4: by turning the screw the balls move out

Return tube designs are simpler to produce, larger in diameter and typically less expensive. Nuts with ball deflectors are more compact, and offer higher speed ratings and smoother motion. In both cases the balls carry the axial load and typically these are the first parts to wear off due to material fatigue. Ballscrews are not designed to withstand significant side or radial loads, those are sustained by the guide ways, which generally exhibit equal load capacity in any direction. The linear motion drive needs lubrication all the time. Lubricant reduces heat build-up, eliminates micro-welding and prevents corrosion. Failures of this part were seen if the spindle went dry or the grease has become resinous. The grease will deposit to the ends of the screw over the time because of the spindle movement. When the balls run dry the spindle surface start pitting.

In the Alliance system the spindle is driven by a stepper motor. When the spindle turns it moves a ball screw that is connected to a barrel. The connection between them is only a pin-port without screws and the barrel is positioned by a slide bearing that prevents it to turn sideways. The barrel can slide forward to a certain point and compresses a spring during it´s movement. This spring pushes the barrel back when the lead screw moves backwards. The plunger is mounted on top of the barrel. The forces from the spindle drive are absorbed by a large support bearing that connects to the chassis of the torpedo. Pictures of the drive are shown below.

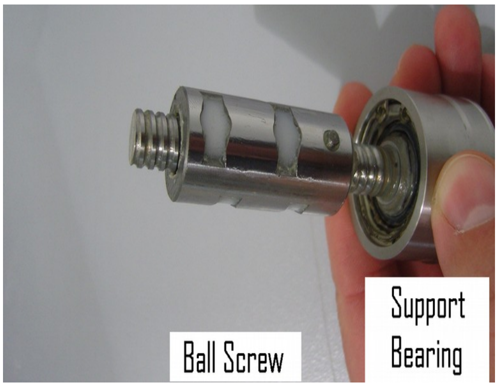

Figure 5: Alliance Ballspindle drive


Figure 6: Motor drive mount

If we want to calculate the maximum possible pressure, I like to explain this with a quite simple model that everybody can follow. The parameters for our calculation are

spindle diameter = 10mm => radius = 5mm = 0.005m
lead per turn = 2.5mm
stepper motor torque = 0.7Nm
plunger diameter = 1/8inch or 3.175mm / measured 3.14mm

First we calculate the mechanical gear of the spindle drive. The gear is the ratio of the distance that the ball moves to the distance that the lead screw moves. The distance for the ball is the slope (ramp) that it moves during one turn of the thread rod.

The formula is ratio = sqrt((pi * 10mm)^2 + 2.5^2) / 2.5 = 12.5 / 1.

In this example I rounded the numbers. The result should be good for an approximation of the theoretical possible pressure.

Now we calculate the force that the stepper motor can apply to the plunger. We imagine a static model where the force that is applied to the plunger is equal to the force that is applied by the pressure of the liquid. The data sheet of the stepper motor says it has 0.7Nm torque. That is comparable with a weight of 70g that is mounted on a 1m long lever that is attached to the motor drive shaft. Now the lever is the spindle radius and we calculate the force that push the ball (0.7Nm / 0.005m = 140N).
Fortunately there are plenty of balls in the spindle that share the forces. Because of the mechanical gear of the spindle drive we get (140N * 12.5 = 1750N). When this force is applied to the plunger we get the maximum theoretical pressure of

1750 N / pi * 10^5 * (0.003175m / 2)^2 = 2210bar

This result shows the hidden resources of the pump drive, but in practice the model is non static and we have some losses. The efficiency of the ball spindle drive is usually better than 90% and the motor needs to compress the spring that pushes the barrel back. The ball spindle drive in the Alliance is rated by the vendor with 1950N dynamic load @ v-max and 2700N under static conditions. From that point of view there is no danger. In practice the stepper motor is maxed out between 1300 and 1600bar, depending on the flow rate.

3 Flow Rate versus Pressure

There is one section left and this is quite emotional. The marketing of the new state of the art instruments have now started a new approach to promote their latest products. Sometimes they leave the scientific pathway that makes it some kind of intellectual undemanding. Lately, Agilent ran a marketing campaign “the uplc debate is over”.

This video is funny, but it has nothing to do with your work in the lab. Agilent is now on top regarding high pressures, that´s all. They argue that the Agilent 1290 is superior because it can pump the highest pressure and flow compared to other systems on the market. That might be true, but pressure and flow alone is not the most important thing. I personally don´t know a customer who uses or needs such high pressures. Now I like to talk about the Alliance chart below, “flow rate vs. pressure”.

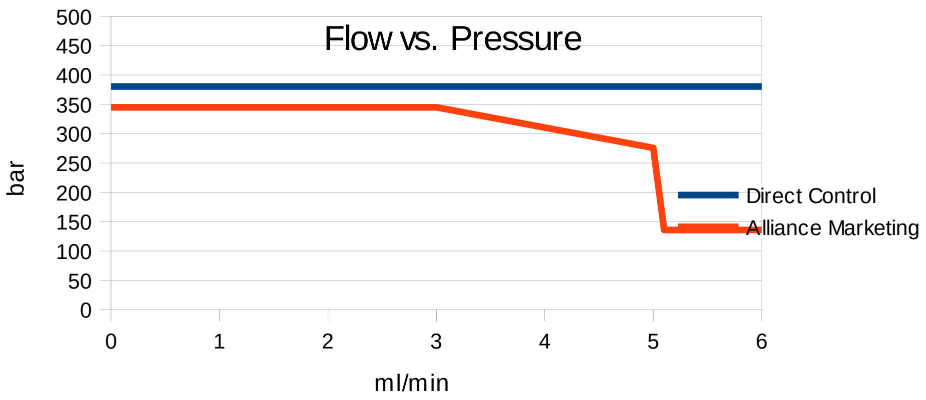

Figure 7: Flow vs. Pressure

The red line shows the pressure that is specified by Waters. The blue line is the pressure that you can run by using the instrument offline via the keypad. The system will show system overpressure when it reaches 380bar. This means that you can use a higher pressure as specified. Another strange thing is that the overpressure error will appear at 380bar, but when you bring the system online, the software will limit the max. pressure to 345bar. The red line ramps down from 345bar@3ml to 267bar@5ml. That would indicate that all the motor power is used. But why does the line show a drop after 5ml/min? Somehow, the red line doesn´t make sense. Many questions, lets do a short calculation.

The Alliance stepper motor has a rated power of 56W and we calculate the available force by using the approximation av_force = 1750N * 0.9 -250N = 1300N. The spindle efficiency is

90% and 250N are used to compress the spring and compensate friction. From physics we know the formula “pressure = force / area”, “work = force * way” and “power = work / time”.

If we want to know whether the Alliance could do 1201bar @ 3ml/min, we need to calculate the required force and power.

Force = 1201 * 10^5N/m^2 * (0.003175m / 2)^2 * pi = 951N

If the pump delivers 3.000µl/min, the 1/8” plunger moves 0.379 m/min forward.

Power = 951N * 0.379m / 60s = 6.02 Watt

This calculation shows that the Alliance pump has no problem to do it and can outperform Agilent's 1290. Because of the relative low power consumption, the pump motors stay cool during operation. If you run the Alliance 24h at 600bar, the motors have ~ 30°C, measured by a infrared thermometer.

4 How does the pressure upgrade work?

I got the idea when I simulated the pumpdrive in SolidWorks a CAD and simulation Software. In some minutes it was clear that we discovered a secret. What customers don´t know, if they have the Alliance they already have a U-HPLC in their lab! How can it be? The Alliance has the resources build in. The upgrade is installed in 20min and then it can release the power. In general, the upgrade will divide the displayed pressure by two. To do this it reads the readbacks from the transducers, modifies them by a microchip and sends them back to the mainboard. Because of the complex pump technology the division by two alone won´t work. Our upgrade will compensate all parameters and even if you run the pump over the maximum pressure range of the transducers, it will obtain the right flow. If the Alliance is switched on, the upgrade acts as if it is not present and the system can calibrate the transducer offsets as usual. During the operation of the instrument the upgrade can be switched on/off whenever you want. If you want to do a diagnostics test you should switch it off. The upgrade board has a feature to protect the electronics of the Alliance. If you interchange the cables for in/output it won´t work, but you can´t damage the mainboard. All voltages that come in or go out are limited to 5V and 50mA. In case of a short circuit there is a socket fuse of 500mA that will blow.

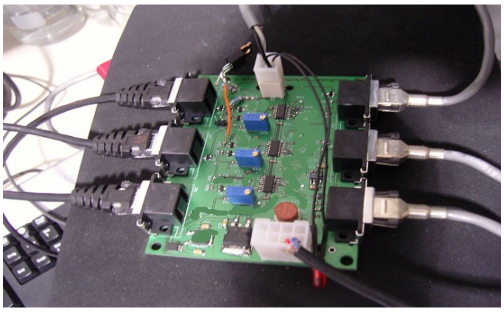

Figure 8: Early prototype of the upgrade board

5 What we claim

Now back to the Alliance system. Is it possible to run 600bar?
The answer is yes, you can do that without compromise.

Can I do 1000bar?
Yes, but you need to change the fittings.

Can it supersede Agilents 1290?
Yes it is able to do this, it will be max out between 1300-1600bar depending on the flow rate.

Our observations are based on the Alliance systems that have successfully done internal tests. **"What we claim: With the upgrade box installed, the Alliance 2690/95 system can be operated up to 600bar with no other changes to the system. You should set a maximum pressure where the pump shuts off."** The customer can use original Waters parts or our fischer analytics parts. We recommend our parts because they have advantages in design. For example, we have designed a special injector needle. The surface is hard coated with a 0,003mm Titaniumnitride layer. TiN is inert to chemicals, lowers friction and protects the needle from damage. The inner bore is passivated by HNO_3. The golden coating looks nice and is used as a wear indicator before replacement. After 5000 injections the needle and the tip looked like new, there was no visible wear off. That makes it difficult to predict the lifetime for this needle, maybe it will last longer than the instrument!

6 What the user should know

We have tortured our test instruments and tried to break parts or tried to provoke a failure. This never happened. We haven´t seen any broken parts or excessive seal wear during our tests. Changing the seals one time per year should work fine.

Fittings: You can work with the instrument at pressures up to 600bar like usual. Your system should be dry and there is no need to change capillary tubes, ferrules or other things. The original seals, check valves and ferrules can also be used up to 600bar. If you replace a ferrule, you can use the improved two piece Swagelok ferrules, these are used as well as in the UPLC instruments.

If you run pressures above 600bar, the risk for a leakage is getting higher. On one of our instruments the prime valve started to leak at 800bar. In that case you need to install a new tip, order the Prime-Vent Valve Rebuild Kit (WAT270936). If you plan to run the Alliance up to 1000bar, we recommend to exchange all standard ferrules.

The cheapest solution is the Swagelok two piece ferrule set. You replace only the ferrule and re-use the nut. All other systems need special nuts and you must buy both nut & ferrule. At places where you sometimes need to open the connection, for example the in line filter, it is a good idea to use a ultra high pressure finger tight nut and ferrule like the Optimize EXP product.

Download the Swagelok catalogue, have a look at page 10,51,52. The same ferrules can be ordered from Waters (700002635), but they are three times more expensive. http://www.swagelok.com/downloads/webcatalogs/EN/MS-01-140.PDF

Optimize Technologies have designed a very good product. I tested the EXP nut & ferrules and never had a leak. Use the following link for more information.
http://www.optimizetech.com/opti-shop/index.php?main_page=index&cPath=7_1088

Idex has a product called LT-135. The lite touch fitting are rated up to 1000bar (15.000psi). Have a look in the webshop.
http://webstore.idex-hs.com/Products/specsheet.asp?vSpecSheet=270&vPart=LT-135x&vFrom=L

Transducers: The Alliance pressure transducers will reach their limit at a pressure of 600bar. Above that pressure the output is not further increased. Because of the non linearity at the end of its scale, it shows a maximum pressure around 280bar. When you test the upgrade the first time, you should run and hold this pressure for a while to inspect all fittings for a leakage. You should set a shutdown pressure 5 bar below the maximum displayed pressure. Then you are safe, preventing a leakage caused by overpressure due to a blocked filter or column. We never had a damaged transducer, even when we were over 1000bar, the risk to damage it is quite low.

High Pressure Motor Valves: During our tests we recognized that one system didn´t inject samples when the pressure was over 300bar. We believed that this was caused due to the motion of the high pressure valves V1 & V2. You can see a pressure gain and pressure drop during the injection cycle that is related to the movement of the high pressure valves. The valve spool acts like a plunger and compresses the fluid when it moves the spool out or opposite when it moves in. Figure 12 and 12 show the movement.

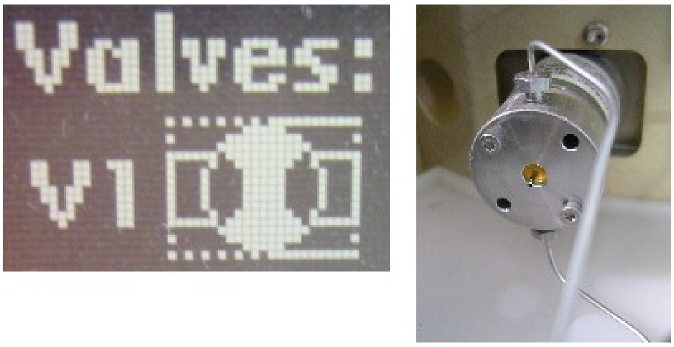

Figure 9: Valve closes, spool moves out

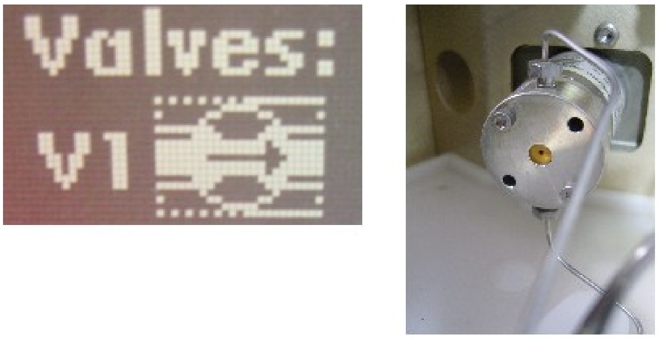

Figure 10: Valve opens, spool moves in

Calculations have shown that the forces applied to the spool caused by the pressure gain are too low to be responsible for the injector failure. We found later that the reason was a dry spool thread. Solving this problem is quite simple, you only need to put grease into the spool thread and that will lower the friction (reduce the needed motor torque).

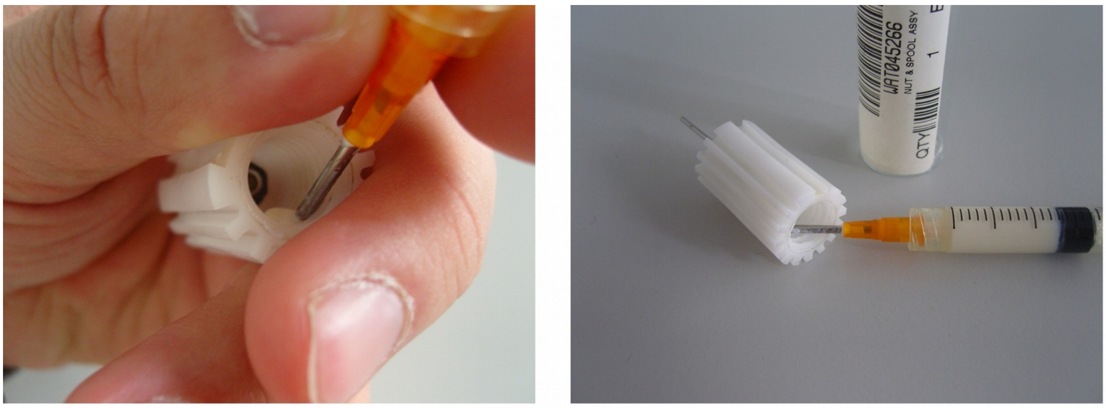

Figure 11: Lubricate the thread with grease

7 How to order the upgrade

We have distributors worldwide who help us with the marketing. Please have a look at our website which distributor is responsible for your country. If you like to distribute our products, please contact us.

This upgrade has a legal protection of registered designs, file 202010003653.4 and patents are pending.

The upgrade will be available in june 2010.

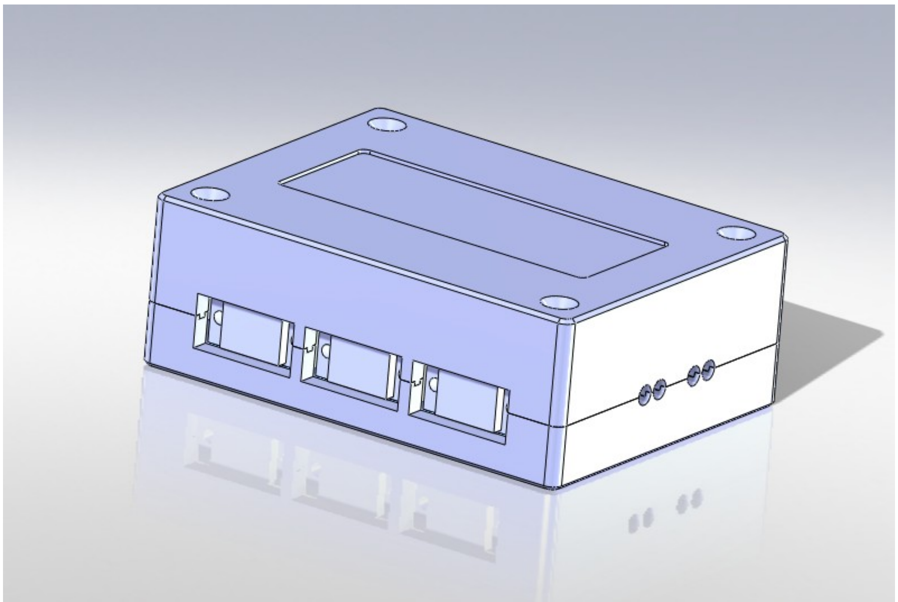

Figure 12: CAD drawing of the upgrade box

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http://shop.fischer-analytics.com