Re-clocking TEAC VRDS-T1 and TEAC VRDS-7

by

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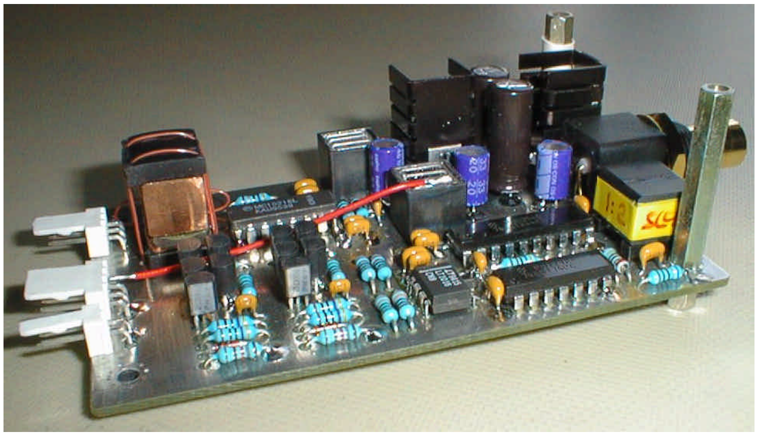

Re-clocking TEAC VRDS-T1 and TEAC VRDS-7

Was it worth it?

This is a description of how I put together the re-clocking device DOO (Digital Output One) in its current version V1.1 and installed it in my TEAC VRDS-T1 CD-transport. The VRDS-7 CD-player is a T1-transport with an audio section added to it, so I will describe how you perform the re-clocking of both the transport and the player. As you may know, the concept of re-clocking is to provide the circuits in the transport or the player with a highly stable master clock and also to use this clock to output a re-clocked S/PDIF-signal to an out-board D/A-converter. Stability in this context means excellent short-term frequency stability, i.e. a clock possessing very low phase noise. Long-term frequency drift is not a big issue in this case, although the frequency of the ECL-oscillator in the DOO changes very little when power supply voltage or ambient temperature is changed. When I purchased the CD-transport I also ordered service manuals for the VRDS-T1 CD-transport and the VRDS-7 CD-player. You won’t need a service manual to re-clock your CD-transport or CD-player as the installation procedure is very simple and straight forward, albeit a bit laborious. If you like to know if I think it was worth the time and effort it took to re-clock my CD-transport, let me put it like this: My impressions after having completed this project was of a calmer and more relaxed reproduction with a broader sound stage. Voices and instruments seems to emerge from distinct positions within the sound stage and remain in place as the loudness varies. Reproduction of nuances and details has improved, especially in the high frequencies. Cymbals and triangles comes through better and are more lifelike. In conclusion, it has become even more fun to listen to my collection of CD’s. So, yes! It was definitely worth it.

Before you commit yourself

Before you decide to embark on this re-clocking project you should have some experience of electronic circuits and schematics, basic soldering skills, at least a digital multimeter if something needs checking and not be afraid to drill a few holes in your equipment. If you don’t, you should consider getting acquainted with someone having these skills. The heart of the DOO, the ECL crystal-oscillator, has a current draw of about 210 mA from the negative VEE-supply and some 190 mA is drawn from the positive VCC-supply as well. This rather high current consumption is necessary to obtain the very low phase noise we are striving for as is explained later on. I assumed the transformer in my TEAC CD-transport wasn’t able to supply that much extra current so I made a simple pcb containing a dedicated raw supply for the DOO. Construction of this pcb may add to the complexity of this project if you are not accustomed to making your own pcb’s. (ECL is short for Emitter Coupled Logic - a logic family from Motorola obtaining its high speed from driving high currents through unsaturated bipolar semiconductors.)

Preparing the DOO pcb

Before you start stuffing the pcb you must cut it to size and drill all the holes as this is not done by the manufacturer to keep costs down. I found the supplied pcb to have a thickness of 1,6 mm instead of 1,0 mm as indicated in the DOO parts list, se reference [1]. This has the effect that if you follow the instructions in the parts list and drill two 1,0 mm holes for the solder pins on the heath sinks for positive and negative regulators U6 and U7, they won’t protrude at the solder side of the pcb. Using a drill with an 1,4 mm diameter solved this problem. I also found two of the four mounting holes for the DOO pcb to be located too close to surrounding components. The hole beside regulator U6 is so close to the heath sink that the mounting hardware I used, threaded hexagonal stand-offs, made contact with the heath sink. As this is in contact with the regulator output it will short the output to whatever the mounting hardware is in contact with, in my case the chassis ground. The stand-off did also rub against capacitor C19 when tightening or loosening. I put some isolation material on the stand-off and managed to get it in a position where it steered clear of the capacitor, see Fig. 1.

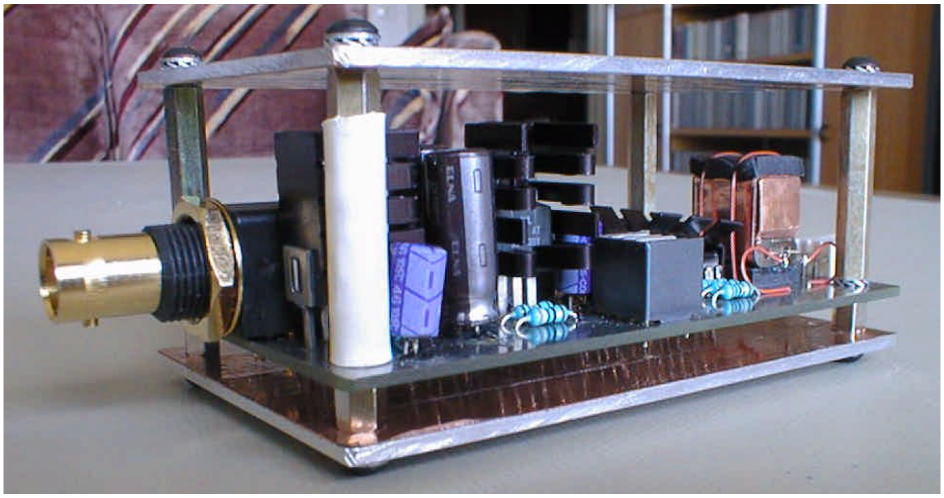

Figure 1 shows the DOO ready to be installed in the TEAC CD-transport or CD-player. Notice the copper rod that has been glued to the crystal and the two lumps of Sorbothane on both sides of the mass loaded crystal.

The other pcb mounting hole is the one close to the Scientific Conversion S/PDIF-interface transformer. This time the stand-off made contact with the component leads of resistor R20 and capacitor C14. I bent the lead of the resistor somewhat to get it out of the danger zone. Apart from this, all was good and well. One more thing though, as I prefer the rugged and reliable BNC pc-mount female jacks made by Vampire, I had to drill two 0,9 mm diameter holes instead of 0,8 mm as indicated in the parts list. The Vampire has a hard gold plating over silver over copper, with brass as the base metal and a Teflon dielectric. (Vampire also makes a nice looking cable mount BNC mail plug.)

Stuffing the DOO pcb

While stuffing the pcb, I took the opportunity to make some improvements as well. I set out by substituting the ACQ-logic, as is recommended in the parts list, with ACT-logic as this should improve the noise figures (ACT has TTL-levels and is faster than HC-logic, see below). Rail noise measured 20 mVpp across the 74ACT74 flip-flops U3 and 50 mVpp across the 74ACT244 buffers U4. These figures where lower than I had expected, indicating good layout and supply bypassing, see also [5]. Then I cut off some traces on the pcb so only one of the eight buffers where left driving the S/PDIF interface transformer. This should improve the noise level further and also improve jitter performance as eight buffers will not turn on and off at the very same instant, se also [2]. Here is how I did it: Pin 9 on flip-flop U3 shall only be connected to the buffer input on pin 8. So I cut of the pcb trace leading to the other inputs (pin 2, 4, 6, 11, 13, 15, 17) and connected them to ground at resistor R23 with a piece of lead cut off. Resistor R22 shall only be connected to the buffer output on pin 12 of U4. So I removed the pcb-trace connecting pin 3, 5, 7, 9, 14, 16 and 18 with pin 12. This modification brought down the rail noise to 6 mVpp across U3 and 15 mVpp across U4. Next thing was to substitute the ACT-logic with F-logic (F stands for fast TTL) as it has been indicated that this logic family adds little jitter if bypassed properly. It was a good thing finding out that rail noise decreased even further, being only 5 mVpp on both U3 and U4. As expected, rail noise at the ECL-receivers was very low, about 2 mVpp. To set these noise figures into perspective, I also measured rail-noise across the two HC-buffers (high speed CMOS) driving the S/PDIF output jack on the servo pcb in the TEAC CD-transport to be 80 mVpp.

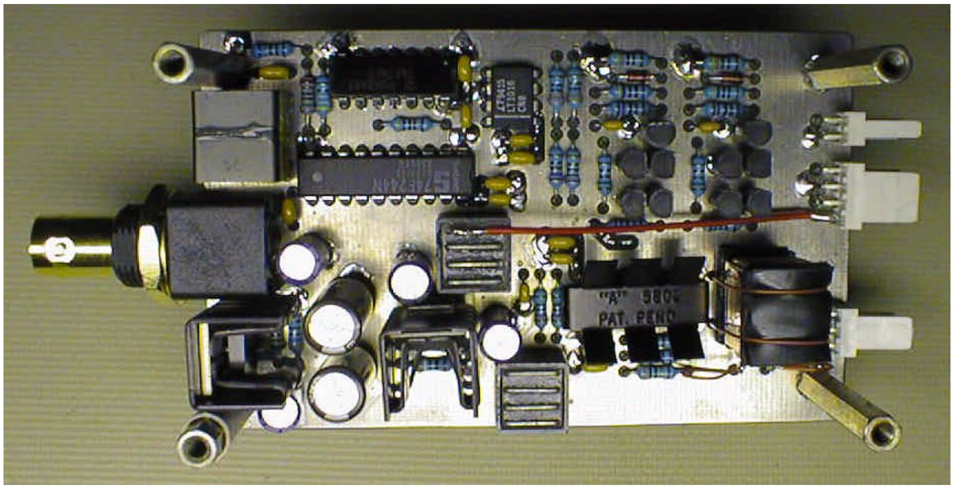

Figure 2 gives an overview of the stuffed DOO pcb. Notice the hook-up wire connecting the VCC-supply to the Molex connector CON3 which feeds +5V to comparator U5 on the servo pcb.

I replaced the 3-pole Molex connector CON3 with a 4-pole of the same make and bent the fourth pin up and away from the ground plane of the pcb, then I connected it with a short run of hook-up wire to VCC-1 on Multi bead L2, see Fig. 2. This way the small pcb, containing comparator U5 and resistors R24 through R27, which resides on the servo pcb will get its +5V feed from the DOO-pcb. I used no sockets for any of the IC's. This is especially important for the two LT1016-comparators which should be located as close to the ground plane as possible. In the Linear Technology Data book the phrase "Do not use sockets." is repeated on almost every page describing this ultra fast precision comparator. By the way, don't forget to connect the small pcb trace from resistor R10 on the component side of the DOO, to the trace on the solder side by a small piece of lead cut off. As you can see in Fig. 1 I made two 2mm copper-clad aluminum plates, 100 x 62 mm, to mount on both sides of the DOO pcb to provide mechanical strength and some shielding. The aluminum plates are connected to each other and to the ground plane on the DOO pcb through the four 30 mm and 6 mm threaded stand-offs, one in each corner of the pcb. From one of the stand-offs a small run of thick ground wire is connected to the chassis of the CD transport via one of the raw supply stand-offs.

Getting the best performance from the oscillator

The easy way is to take the crystal from the servo pcb in the TEAC CD-transport or CD-player, as described in the section covering installation of the DOO further on, and simply drop it into the DOO-pcb. But if you do this, the oscillation frequency will drop (!) some 300 ppm or so. This is because the parallel-resonant crystal was removed from the parallel-resonant circuit in the CD-transport or CD-player and put in the series-resonant ECL-circuit in the DOO. There is no difference in the construction of a series-resonant crystal and a parallel-resonant crystal, which are manufactured exactly alike. The only difference between them is that the series-resonant frequency of the parallel-resonant crystal is set a couple of 100 ppm lower than the desired operating frequency, as described by Matthys [3]. This shall pose no problems if you connect the CD-transport or CD-player to an outboard D/A-converter as long as it conforms to the CD standards maximum permissible deviation of +/- 400 ppm. However, some D/A-converters may tolerate a deviation of only +/- 100 ppm. This is the case with D/A-converters equipped with interface receivers from Ultra Analog as they employ a voltage controlled crystal oscillator in the second phase locked loop.

Considering this, I decided not to go the easy way. Instead I order a crystal for series resonance together with its measured characteristics from Klove Electronics in the Netherlands. If you do this, specify a 16,934400 MHz crystal for series resonance in a HC49-U or HC50-U can with a frequency tolerance of 5 ppm and ask them to measure it up for you and enclose the measurements protocol. The minimum order quantity is one item, production and delivery time is one week within Europe and they charge you less than $20 for this. Klove's home page is http://www.klove.nl. By doing this you will get a crystal which is closer to the desired operating frequency. But most important, you will get to know the value of the internal series resistance of the crystal and must not resort to thumb rules. This is a good thing! Because if you know the exact value of the crystals internal series resistance, you can pick the lowest permissible value for the load resistor and obtain good in-circuit Q without risking to fry the crystal. Hopefully you may be more lucky than I was. I had to order the crystal from Klove's agent in Sweden who somehow forgot to inform Klove to measure up the crystal for me (sigh!).

Understanding the oscillator circuit

When an electric potential is applied across the plates of a piezoelectric crystal it physically bends or deforms. The crystal also exhibits the phenomenon of mechanical resonance when it is excited with an alternating potential of the correct frequency. At low frequencies, up to the series resonance, the crystal is capacitive and above series resonance the crystal becomes inductive. At series resonance the crystal has zero phase shift as its reactive components cancel and the crystal's impedance drops to a minimum which is the crystal's internal series resistance. Crystals have very high Q and crystal Q is important because it controls the short-term frequency stability of the oscillator. The Q of a crystal in a circuit is in most cases less than the Q of the crystal alone, since most circuits introduce resistive losses. (In all oscillators, other than bridge oscillators, the in-circuit Q is less than the Q of the crystal alone.) To minimize these losses we shall keep the resistive value across the crystal's terminals as small as possible. But not to small, we must take care not to exceed the maximum permissible drive power that can be put into the crystal without damaging it.

The ECL-oscillator in the DOO is series-resonant. The crystal is in series with the internal source resistance of the ECL-receiver which is driving it, and the load resistor R1. The crystal acts as a frequency dependent voltage divider together with the load resistor. The input of the ECL-receiver senses the current through the load resistor which reach its maximum at series resonance. For a crystal to control the frequency of an oscillator circuit, it must maximize the oscillator's gain at the oscillation frequency and minimize it at all other frequencies. To give the crystal maximum control of the loop gain, it must have maximum control of the voltage divider, which means that both the source and load resistance should be small with respect to the crystal's impedance at series resonance.

Calculating the minimum load resistance

With this in mind, we may now determine the lowest permissible value of the load resistor R1. If you happen to know the series resistance and the maximum drive power that can be put into the crystal without damaging it you may use these values in the following calculations. Otherwise use the thumb rule given by Matthys [3]: “A typical crystal has about two-thirds the maximum series resistance specified by the manufacturer”. Browsing through Klove's Web-site in search of technical specifications I found crystals with a resonance frequency between 14 and 27 MHz to have a maximum series resistance of 20 ohms, two-thirds of this is about 13 ohms. Maximum drive level was specified to be 0.5 mW at all frequencies.

Matthys also gives a thumb rule for choosing the value of the load resistor: “For series resonance, the crystal's load resistance is usually set equal to or somewhat less than the crystal's internal series resistance in order to get good in-circuit Q. A good compromise is to make the load resistance equal to one-half the crystal's internal series resistance.” Following his advice I found the crystal's maximum drive level was exceeded by a fair amount. I set out by choosing a load resistor value of 10 ohms and measured the voltage drop across it to get the current through the crystal. (As Matthys points out: “Measuring the voltage across the crystal itself is meaningless as a measure of current through it since crystals frequently operate slightly off resonance”.) Then I calculated the crystal's power dissipation as the product of the crystal's internal series resistance and the square value of the current through it. This load resistor value made the crystal dissipate almost 2.0 mW, four times its maximum drive level. I gradually increased the value of the load resistor and calculated the power dissipation of the crystal. Finally I landed at the rather highish value of 30 ohms to get close enough to the desired 0.5 mW of power dissipation. The ECL-receiver must be able to drive this 43 ohms load (13R + 30R) which accounts for the rather high current draw from the VEE-supply as mentioned earlier. The ECL-package contains three receivers in all and runs quite hot, so I put some silicon grease on top of it and pushed on a small heath sink to cool it off a bit, see Fig. 2.

Afterthoughts

I could have saved myself a lot of soldering and measuring if I had made some simple calculations beforehand it seems: The current through the crystal (and the load resistor) is the square root of the crystal's maximum permissible power dissipation divided by its internal series resistance, I = (Pxs/Rxs). With values inserted, 0.5 mW and 13 ohms, we get 6.2 mA. The voltage drop across the crystal is the square root of the maximum permissible power dissipation multiplied by the crystal's internal series resistance, Uxs = (Pxs*Rxs). With values inserted we get 0.081 Vrms. The voltage drop across the load resistor is the voltage drop across the crystal subtracted from the voltage swing of the ECL-receiver (0.8 Vpp or 0.28 Vrms), Url = Uecl - Uxs. With values inserted we get 0.2 Vrms. Finally we get the value of the load resistor as the voltage drop of the load resistor divided by the current through it, Rl = Url/I. With values inserted we get 32 ohms.

Lowering the crystal's sensitivity to microphonics

The crystal must be protected from sound waves and mechanical vibrations as they cause frequency modulation of the oscillator. Hence, acoustic shielding and shock mounting are a must for the crystal as pointed out in [1]. I glued a piece of square copper rod to the crystal's can to add mass and put small lumps of self adhesive Sorbothane on both sides (up and down) of the crystal package, see Fig. 1 and 2. I placed the package on the DOO pcb, wrapped two lengths of very thin wire around it and then through the holes in the pcb where the crystal is to be located. Finally I secured the package to the pcb by twisting the wires together on the solder side of the pcb, but left it loose enough to be able to move on its Sorbothane lumps. The crystal leads were connected to the pcb with the same type of thin wire used to secure it, the wires were bent in small loops so as not to prevent the crystal from being able to move.

Installing the DOO pcb

The only suitable place to put the DOO-package and its raw supply in the CD-transport or CD-player is underneath the servo pcb to the right of the VRDS mechanism, see Fig. 3.

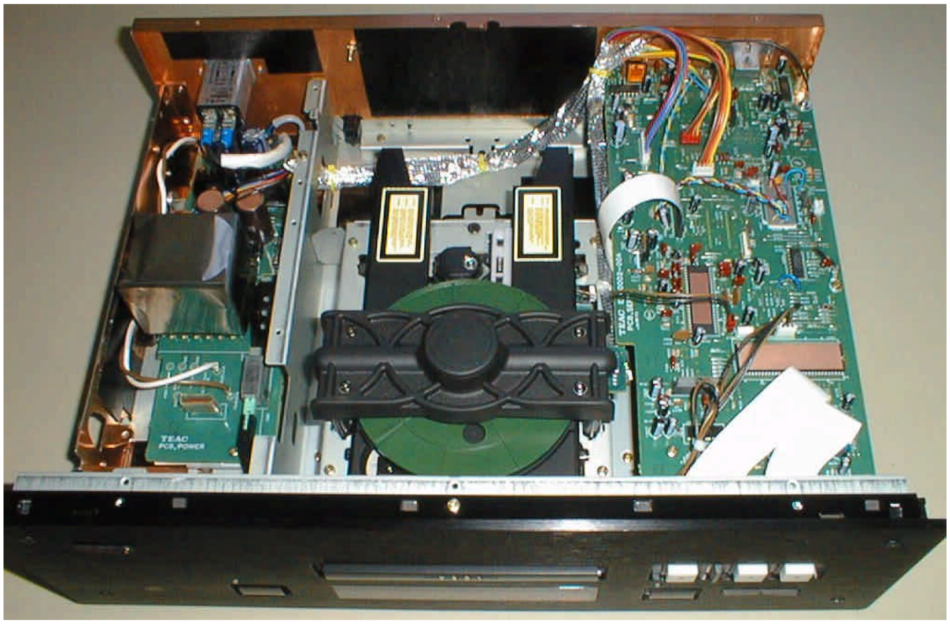

Figure 3 reveals the innards of the TEAC CD-transport. To the left is the power pcb, in center is the VRDS mechanism and to the right is the servo pcb.

So I removed the cover and top chassis of the CD-transport, pulled out the connectors from the servo pcb, unscrewed it and lifted it out. Then I disabled the crystal oscillator by unsoldering crystal X51, capacitor C51 and C55 from the servo pcb (crystal X51, capacitor C51 and C52 if you have a CD-player), see Fig. 4. The capacitors and the 16,9344 MHz crystal went into the dustbin, but you may retain the crystal and use it in the DOO pcb as described in the section "Getting the best performance from the oscillator". These components are located close to the data-decoding chip U403, an 80-pin IC mounted on the solder side of the servo pcb. This was very foreseeing by TEAC as it provides ample space on the component side to mount the small pcb containing comparator U5 and resistors R24 through R27 close to the crystal input (XTAI-pin) on U403. I attached this pcb to the servo pcb with a piece of double sided self adhesive tape, see Fig. 4. TEAC also drilled a 10 mm hole in the servo pcb, close to connector P401, to pull through the four twisted wires from the U5-pcb to CON3 on the DOO pcb, see Fig. 6.

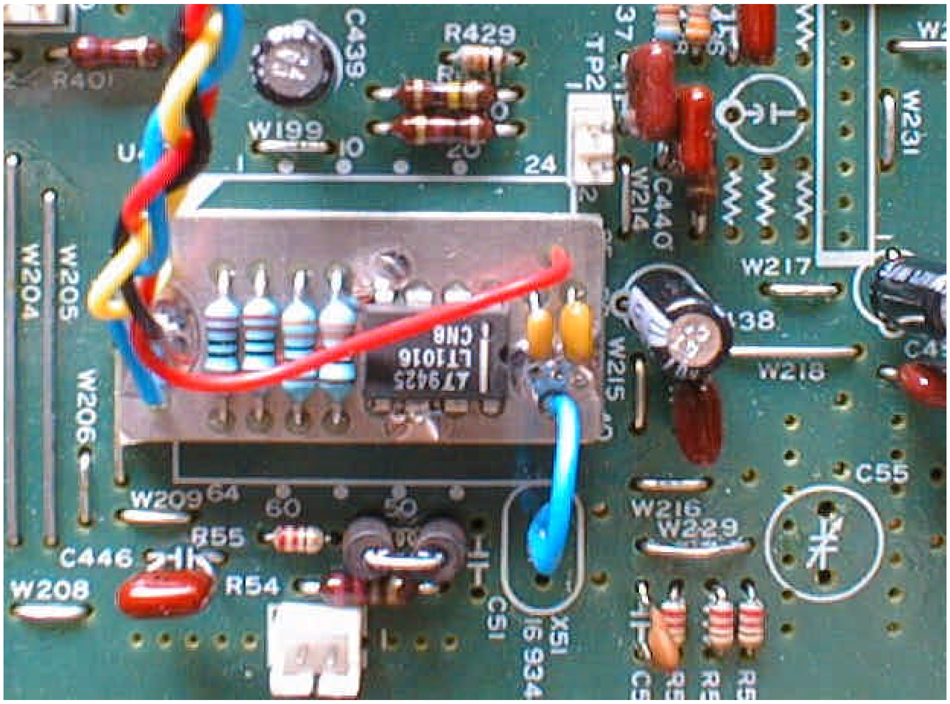

Figure 4 shows the placement of the small pcb containing comparator U5 which feeds the master clock to the XTAI-pin of U403. Notice the locations of the unsoldered components: crystal X51 and capacitors C51 and C55, as is indicated on the silk screen.

The next thing on the agenda was to find out where on the servo pcb to tap off the S/PDIF-signal to be re-clocked by the DOO and presented on the BNC female jack CON1. Close to the rear panel the placement of connector P415 is indicated on the silk screen. Lucky for us TEAC left this one out, so it provides a convenient way to tap off the S/PDIF-signal and connect it to CON 2 on the DOO pcb, see Fig. 5. I soldered the wire carrying the S/PDIF-signal (same as the DOBM-signal in [1]) to the hole marked 1 and the other to the ground connection marked 2 on the silk screen. I twisted the two wires together and run them through the aforementioned hole in the servo pcb. Finally I punched a 12 mm hole in the rear panel of the CD-transport and secured the DOO-package to it by means of its BNC female jack. The DOO-package was mounted upside down (i.e. with the components facing downwards) so the mass loaded crystal is hanging in its Sorbothane suspension rather than resting on the pcb.

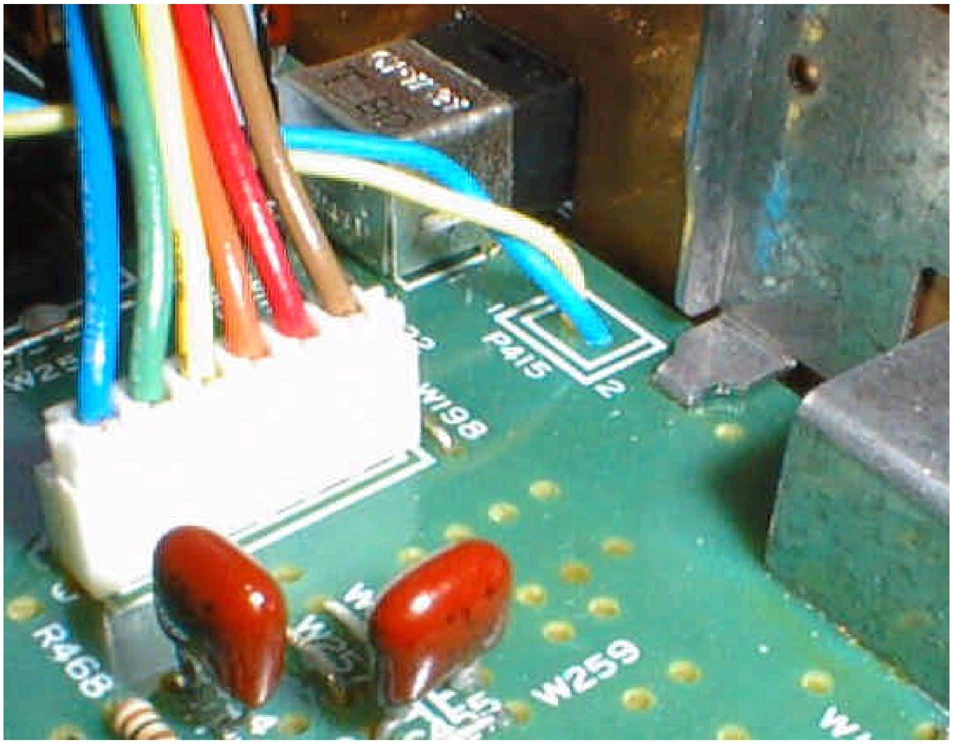

Figure 5 shows the location of the absent connector P415 where the S/PDIF-signal to be re-clocked is tapped off.

Providing the DOO with a dedicated raw-supply

I tapped off the mains AC for the DOO raw supply by soldering two wires to the pins where the AC mains cable enters the power pcb in the CD-transport, see Fig. 3. The connection was made before the power switch so as the DOO is always powered on even if the CD-transport is switched off. This way the oscillator has warmed up and is stable whenever I decide to spin a CD. The wires carrying mains AC to the DOO is run between the chassis and a sheet metal profile alongside the bottom of the chassis and the rear panel providing shielding and protection. Mounting the raw supply pcb was rather tedious as the main chassis is not level at all places and most of the CD-transport had to be disassembled prior to drilling.

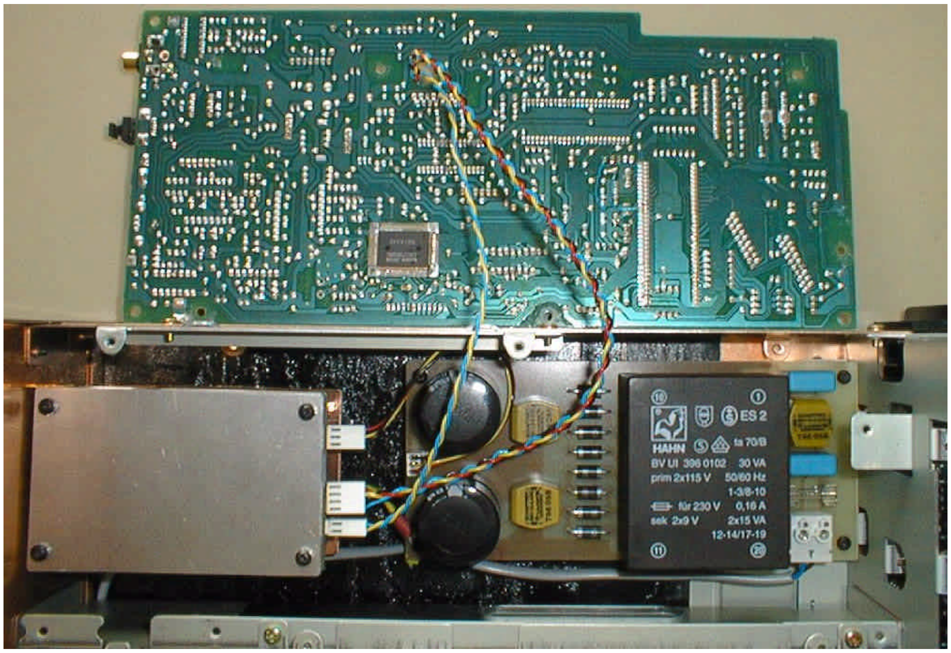

Figure 6 shows the installment of the DOO and its dedicated raw supply underneath the servo pcb in the TEAC CD-transport. Notice the hole in the servo pcb where the wires from the DOO is pulled through.

As you can see from Fig. 6 I used a Hahn pcb mount potted low profile transformer with two 9V secondaries rated at 15 VA each. A simple mains filter was put together with two 0.01 uF Wima capacitors and a 2x39 mH common mode choke from Schaffner, a mains fuse and a pcb connector for the AC. Each secondary has a rectifier bridge with four GI856 diodes, followed by a 2x39 mH choke and a 4.700 uF electrolytic. The raw-supply provides about 11 V for the VCC and VEE, giving a voltage drop across regulators U6 and U7 of 6 V. This makes the regulators run very hot as they have to dissipate 1.2 W each.

Checking it all out

Having completed the installation of the DOO and its raw supply, it was time to verify the installation. I measured the oscillator frequency to be 16,933998 MHz, see Fig. 7, which is about 24 ppm lower than the specified resonance frequency.

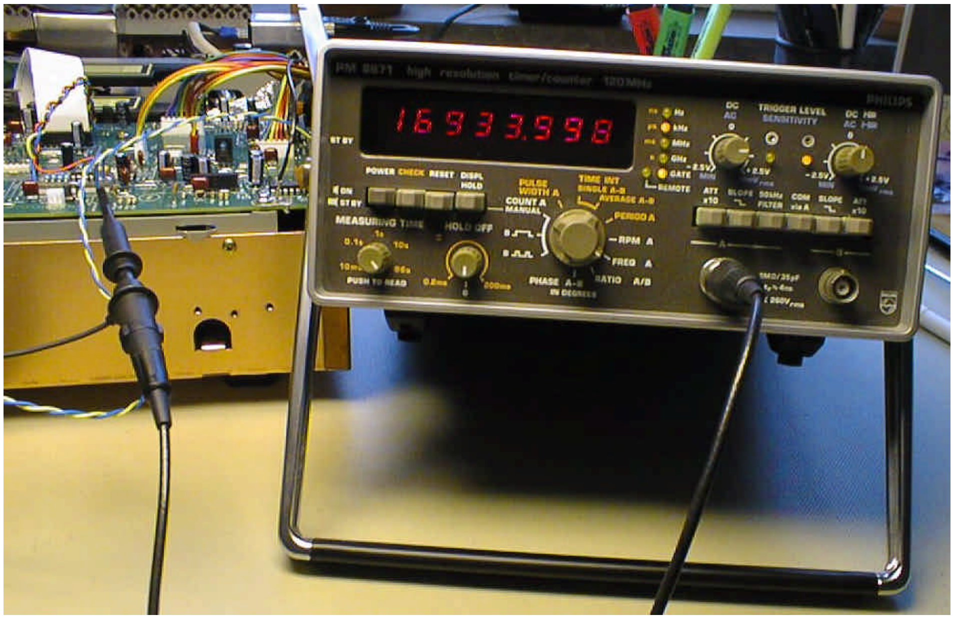

Figure 7, measurement of the oscillator frequency showed it to be 24 ppm too low.

Then I checked the time alignment of the master clock and the S/PDIF-signal with an oscilloscope. I connected one probe to the master clock as it enters flip-flop U3 on pin 11 and the other probe to the S/PDIF-signal as it enters the flip-flop on pin 12. On the oscilloscope photo in Fig. 8 you can see the two signals as they are about to enter the re-clocker. The rising edge of the S/PDIF-signal lags the rising edge of the master clock by a small amount, indicating that the re-clocker may not perform at its best.

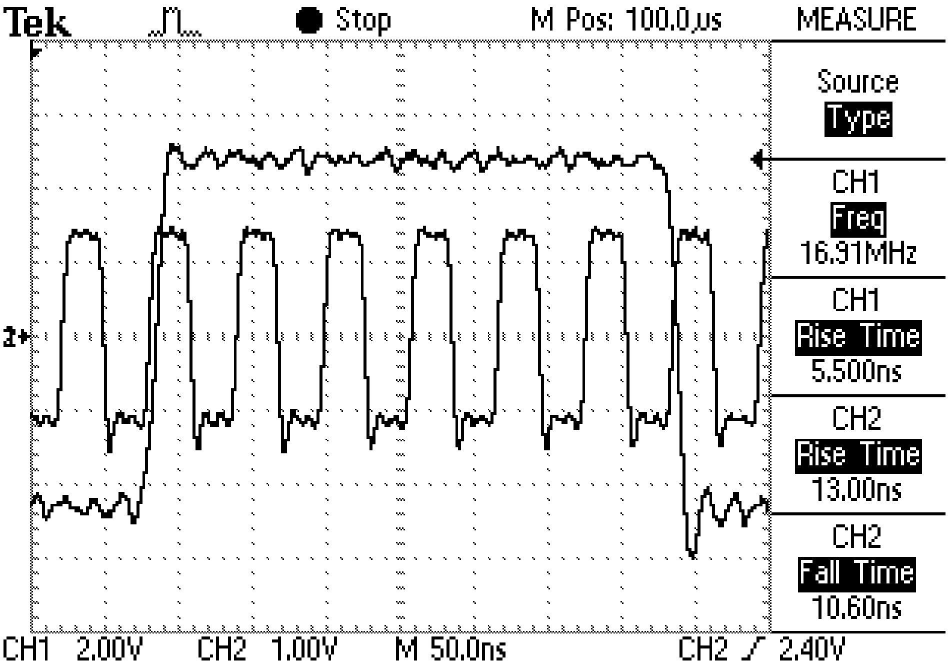

Figure 8 oscilloscope view of the master clock and the S/PDIF-signal as they are about to enter the re-clocker.

So I changed places of SYSCK+ and SYSCK- in the CON3 female connector to get a 180 degree phase difference between the SYSCK and RCCK clocks as is recommended in [1]. On the oscilloscope photo in Fig.9 you can see that the S/PDIF-signal now is stable some 25 ns before the rising edge of the clock signal, indicating good operation of the re-clocker. (Horizontal resolution is 50 nanoseconds per division, vertical resolution is 1V per division for the S/PDIF signal and 2V per division for the master clock to clarify the relation between the two signals.)

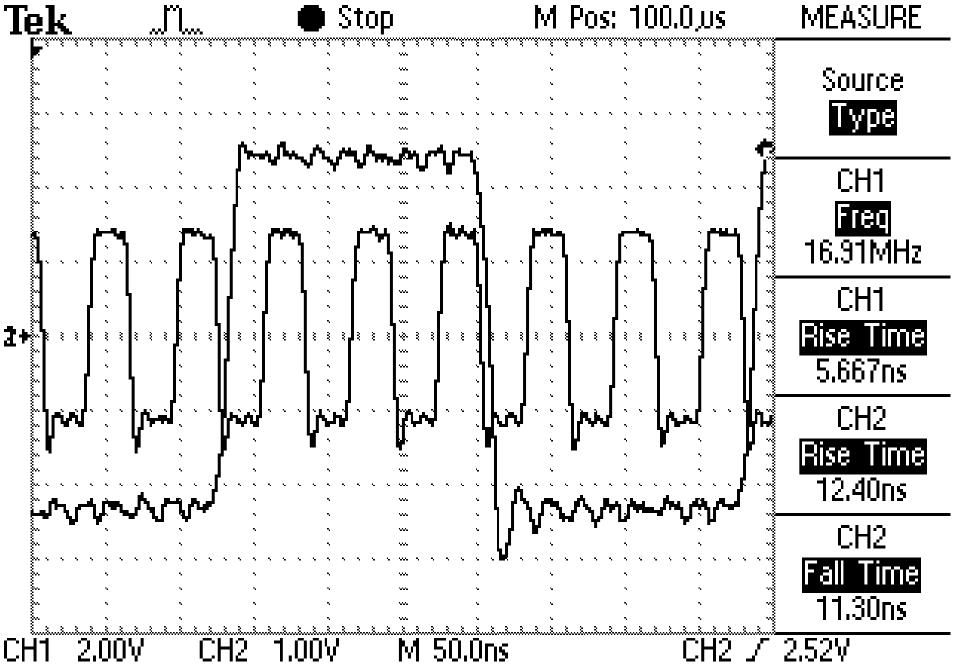

Figure 9 oscilloscope view of properly aligned master clock and the S/PDIF-signal as they are about to enter the re-clocker.

This completes my essay on re-clocking the TEAC VRDS-T1 CD-transport and the VRDS-7 CD-player. If you plan to re-clock your CD-player and make use of its built-in D/A-converters you may no doubt experience an improvement similar to what I described in the beginning of this paper. However, you may consider a more ambitious scheme, such as re-clocking the D/A-converters as close to the D/A-chips as possible. This means re-clocking both the digital data, the left/right-clock and the bit clock as is outlined in Paul Winser's paper [4].

If your TEAC hums.....

If you don't decide to re-clock your equipment, you may perform this modification anyway. This is a quick and easy one! If the mains transformer in your CD-transport or CD-player produce a loud acoustical hum, it is because the transformer is bolted to the chassis and makes the whole case resonate with the AC mains frequency. If you have an Audio Quest Sorbothane isolation disc to spare, why not place it under the transformer and get rid of the hum!? This is how to do it: Remove the cover and the top chassis, to the left of the VRDS mechanism in the T1-transport you will find the power pcb with the power transformer amidst it, see Fig. 3. If you have a VRDS-7 CD-player, the power pcb is located at the rear, behind the VRDS mechanism. (The audio pcb resides at the left of the mechanism.) Remove the screws securing the power pcb, including those securing the power transformer via a plastic transformer base to the chassis. Carefully, so it won't break, loosen the plastic power switch rod from the power switch on the pcb and unsolder the mains connections. Pull out connectors P601, P602 and P603 (P602 and P603 if you have a CD-player). Now you shall be able to lift the power pcb off the chassis and put the Sorbothane isolation disc where the plastic transformer base used to be. Reinstall the power pcb by putting back the power switch rod, the connectors and the remaining screws securing the power pcb to the chassis, finally solder the mains connection to the pcb. (Do not put back the two screws that secured the transformer to the chassis!!!) When this is done you will not hear the faintest hum, not even if you place your ear close to the CD-transport or CD-player. If you look at Fig. 3 you may notice some minor modifications to the power supply in the CD-transport. I have replaced the AC mains inlet with a filtered one from Littlefuse, wrapped the transformer in my-metal sheets to provide magnetic shielding and replaced the rectifier diodes with four GI856.

References

[1] “Digital Output One V 1.1” by Erland Unruh, 1994.

[2] “DOO 1.1 Rev 1” by Erland Unruh, 1996.

[3] “Crystal Oscillator Circuits” by Robert J. Matthys, John Wiley & Sons, 1983.

[4] “CD Jitter” by Paul Winser, 1993.

[5] “Taking the X-DAC 3.0 one step further” by Erland Unruh, 1997.