Understanding Digital Clocking
and its Application in the *dCS* Verona Master Clock

Why must everything be "locked" together?

This is pretty basic and applies to all separate transports and DACs, not just dCS. But we will use a dCS Verdi Transport, Purcell Upsampler, and Elgar DAC for our example.

Imagine the data coming off the CD as a flow of water, and the Verdi, Purcell, and Elgar as a series of cascading buckets, each with a spout feeding the following bucket. The data flows from the Verdi to the Purcell, and then on to the Elgar. The rate of flow out of each bucket is determined by the spout *(clock).* As long as the rate of flow is *exactly* the same out of each bucket, everything works smoothly. Any individual bucket never overflows and never runs out of water.

In this case, each bucket has it's own independent clock *(spout)*. It's not a perfect world *(even in digital).* No matter how hard you try, you cannot adjust all three spouts perfectly. Thus, eventually one of the buckets will overflow or run out of water. When this happen in a digital system there will be a glitch – a noise of some sort.

This can be easily be demonstrated by using a Verdi playing an SACD and an Elgar in Master Mode. Remove the clock link between the Verdi and the Elgar. Now, dCS components are good, but not perfect. There will be a small discrepancy between the two clocks, on the order of several ppm *(parts per million).* This is sufficient to cause the data bucket in the Elgar to fill *(or empty)* in about 20 minutes – at which point the data stream is interrupted *(splat)* and the bucket reset, only to glitch again in 20 minutes or so.

How were the components locked together prior to the Verona?

Typically digital components use a PLL *(Phase Locked Loop)* circuit to "recover" the clock from another component in the chain, thus insuring that all are using the same clocking information.

In the default configuration of a Verdi, Purcell, Elgar system, the clocking is provided by the Verdi Transport. It is recovered from the Verdi's data stream by the Purcell. The clocking information in the Purcell's data stream is then recovered by the Elgar. In the dCS components, this method provides extremely good performance and the ultimate in flexibility, as *any* upsampling rates may be used. The downside is that the "time/distance" between the clocking of the original source and the DAC presents some performance problems – phase issues, jitter, etc.

If one is willing to live with upsampling data rates that are limited to exact multiples of the source data rates *(that is, on a 44.1 CD, 176.4 would be acceptable, 192 would not)*, an alternative clocking arrangement provides superior performance. In this case the Elgar is used in Master Mode and provides a clocking signal for the Verdi Transport. The advantage of this system is that, at the end of the chain, the Elgar is allowed to use it's own clock *(rather than having to recover a clocking signal originally provided by the*

Verona). The Elgar's clock provides several advantages. It is more accurate, and it is in a quieter environment, away from all the electrical and mechanical noise found in the transport. But most importantly, since it is free to run on it's own, the time/distance *(or phase)* problems are no longer an issue.

Thinking of this arrangement in terms of our bucket analogy, the clock link between the Elgar and the Verdi allows the Elgar to control the rate of flow out of the Verdi "bucket." The Purcell bucket sets it's flow by recovering the clock from the Verdi data stream *(which was clocked by the Elgar)*. The Elgar bucket doesn't have to worry about *any* of the flow rates, because it set the Verdi flow rate to start with, thus leaving the Elgar free to use it's own clock.

Does that make sense? Good. This takes us to the point at which *Stereophile* said, *"It doesn't get any better than this!"* …and we foolishly thought they were right.

The Verona Master Clock

Obviously dCS has always had an interest in digital clocking issues. They manufacture master clocks that are used in the professional recording industry. For years audiophiles in Japan have been using dCS pro master clocks to link dCS components in their home systems. While we always thought that was overkill, recent advancements made by dCS on clocking *(and incorporated into the Verona)* have now made the performance advantage of a separate master clock undeniable.

The complete story behind the Verona may never be told, as dCS considers it a trade secret. However they have been willing to share a limited amount of very interesting information.

Let's look at the apparently obvious advantages of the Verona. First, it is operating in a very low noise environment, away from not only the noise of the transport, but also the digital noise of the DAC. Secondly, the Verdi, Purcell, and Elgar are all locked to the same clock. This means that any remaining jitter is in phase throughout the chain and becomes largely irrelevant. And finally, the Verona is a "Class 1" clock and thus extremely accurate. But this is where "common beliefs" and the strange world of dCS begin to diverge.

Contrary to what one might be led to believe by reading spec sheets, it is not particularly important that a clock be extremely accurate. People with "perfect pitch" can identify a semi-tone *(0.02% or 200ppm)* – the difference between a black and an adjacent white key on a piano. So it is reasonable that a digital clock needs to be at least an order of magnitude better than that, say 10ppm. The spec on the Verona is better than 1ppm… more than good enough. Atomic clocks with ppb *(part per billion)* are a bit over the top.

More important than absolute frequency accuracy is frequency stability. The human ear is an integrating device and looks at *(listens to?)* data over large parts of milliseconds. Thus it is very good at spotting anomalies and structure but relatively insensitive to wideband noise. For example, some people complain about idle tones *(a common artifact of digital processing)* at –110dB but don't even notice a –110dB integrated noise floor. For those of us conditioned to thinking in analog terms, it's the equivalent of being more irritated by a low-level 60Hz hum than a similar level of white noise.

> So, given this, the clock has to be sufficiently stable not to have any glitches *(a trivial task for dCS)*; but, at the same time, not have "structure" that might be discernable to the ear. Some ultra-stable clocks behave in such a predictable and repeatable manner that their use can actually result in just the type of idle tones mentioned in the previous paragraph.
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> So, one of the secrets behind the Verona is the deliberate addition of random noise to the clock signal. You could think of this as being roughly equivalent to the addition of dither to a digital audio signal. One would think that an "all-or-nothing" digital signal has a well-defined noise floor. However, since the early days of digital it's been known that adding random noise (dither) to the signal allows data below the theoretical noise floor to be recovered. The same is true in clocking. There are some unusual behaviors that actually allow a more accurate clock signal to be recovered if the original clock signal is made less accurate through the intentional addition of controlled noise.
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> Take, for example, the inherent limitations of a PLL circuit. The clock signal provided by the Verona is recovered in each individual component by a Phase Locked Loop. PLLs have a limitation similar that is similar to "crossover" or "notch" distortion in a class B amplifier. That is, there is a small "dead" area in the center of the PLL's operating range. If the clock signal is drifting within that dead zone, no action is taken by the PLL to center on the signal. So, in a perverse sense, it is better to add random noise to the clock, continually forcing it out of the dead zone *(and allowing the PLL to better do its job)* than it is to further improve the stability of the clock, only to have it spend even more time in an unknown position within the PLL dead zone.

Here's a little story that sums things up. During a recent trip to the dCS factory we were given an explanation of the Verona by a dCS engineer. Following that discussion a member of our party said, in a rather bemused tone, *"So in the Verona you have created an ultra-quiet environment… so you can add noise… to make the clock ever so slightly less accurate… so it can be more accurate. Right?"*

To which the engineer smiled and replied, *"I think you've got it!"*

Obviously this is a gross oversimplification of the techniques employed within the Verona. However, it does point out that even in digital *(especially in digital?)* things are never as simple as they might first seem.

While it might be interesting, on a purely intellectual level, to explore these technical issues, the proof is always in the listening. In the end, it always comes back to one simple fact. If it doesn't sound better then it isn't better. We therefore invite you to listen for yourself.