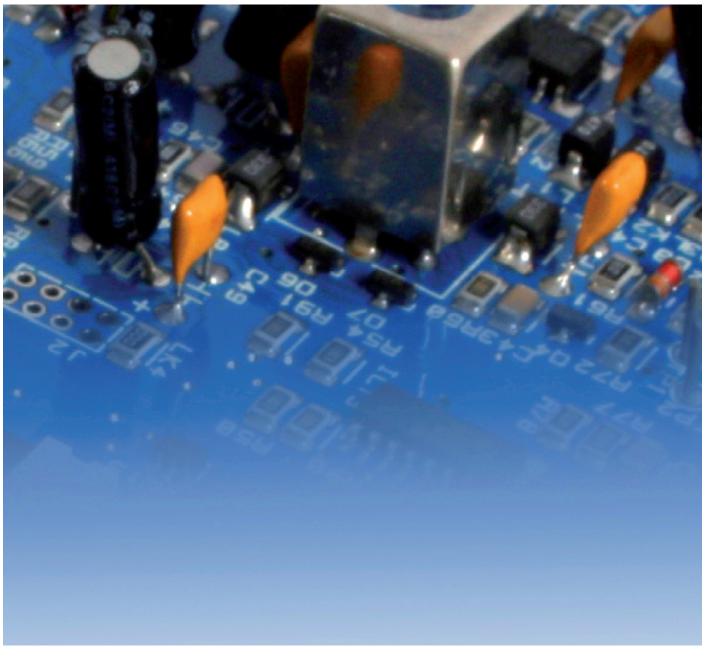

# Digital Conversion

## The Focusrite Approach

**Richard Elen and Rob Jenkins unveil the design principles and approaches behind successful digital conversion systems.**

For many years there has been a kind of mystique surrounding digital audio conversion: the act of converting analogue signals to digital, and vice versa. The vast majority of this mystique derives from the earlier days of digital conversion, when the subject was a good deal more arcane and mysterious than it is today. Industry use of digital audio technology only goes back forty years or so (unlike analogue audio, which dates back to the middle of the 19th century), and in the early days — and for a comparatively long time afterwards — the significant parameters that directly affected conversion quality were simply not fully understood. The role of jitter in muddying the sound and introducing intermodulation distortion was not fully realised, for example. Indeed, clocking as a whole was not given the attention it deserved. The first (analogue) imaging and reconstruction filters to do their job without introducing significant phase distortion were designed by essentially breaking the rules and seeing what happened; learning how to effectively dither a digital signal was the sort of thing audio engineers picked up in Dark Arts classes at Hogwarts.


**The ISA One Digital: a modern mix of high-quality analogue and digital technology.**

Today, digital audio as a whole is a lot better, and more widely, understood. Fundamental conversion components offer a level of performance far in advance of what they were only a decade ago.

> “there really isn’t any magic to good conversion: it’s simply a matter of taking care and not cutting corners”

We know how to implement a good phase-locked loop for effective clock recovery and jitter minimisation. Not only have higher sample rates given us much more room to implement high-quality filters; we’re better at designing them too, and we know how to build a digital filter that suffers from few of the challenges that faced our predecessors, so much so that today’s D-A designs can actually clean up filter problems in earlier digital recordings. We also know that there really isn’t any magic to good conversion: it’s simply a matter of taking care and not cutting corners.

### Advances In Silicon

The starting point for any new conversion system is to consider the conversion chips available at the time a product is being designed. New, more advanced parts come out, on average, every couple of years, each offering better performance than the last, and pushing back the boundaries of converter design. Smaller audio companies can take advantage of these almost immediately and design a product around them, whereas the giants of the industry can be slower to respond for reasons that go beyond the technical domain, such as procurement practicalities.

It’s the chips that define the practical limits of a conversion system’s specifications — in particular the dynamic range — and any self-respecting professional audio company will research the available parts at the time they are planning a new product, and determine what offers the best performance (and possibly the best value for money). Exactly what the chip is — what its type number is, or who made it — is rather less important. If you're dealing with a professional manufacturer, then the answer to the question "what converter chip do you use in this product?" is likely to be, "the best available part for the job". In a similar sense, you really don't need to ask BMW whether the engine they have built their new model around is up to the job: you can happily assume that it is.

The boundaries of converter chip design are being pushed back all the time, and the main impact of these developments is improvement in the dynamic range offered by the part. Current converter chips offer around 121—123dB in this area; however the theoretical maximum for a 24-bit system is 144dB. There is quite a way to go before we approach that limit, and each time the performance moves forward, it's the result of analogue as well as digital developments.

**The epitome of modern converter design: The A-D/D-A option card for the ISA428 MkII and ISA828 provides Focusrite's multi-channel preamps with 192kHz/24-bit digital outputs with a dynamic range of 122dB.**

## Analogue Is Critical

At the same time, just having a good quality conversion part on the circuit board does not make a high-quality converter: there is still a very distinct art and science of conversion design, which manifests itself at several levels, not least board layout and circuit design. Some early manufacturers of digital studio equipment believed that with the advent of "pure, perfect" digital sound, analogue design would no longer be as important, but today we know that in fact, if anything, the opposite is the case. Above all, developing a clean, well-designed analogue section is vital.

> "just having a good quality conversion part on the circuit board does not make a high-quality converter: there is still a distinct art of conversion design"

As part of this process, the analogue section needs its own power supply regulation too, as power supply lines — and the supplies themselves — can introduce noise. Indeed, power supply noise is one of the biggest factors affecting the noise floor. Traditionally it was felt that power supplies had to be linear, as early switch-mode designs often raised the noise floor by inserting (and sometimes even radiating) digital noise into the system. Today, however, switch-mode PSU design has advanced to the point where they actually reduce noise: a modern switcher simply takes the noise out of the audible range.

## PRINCIPLE INTO PRACTICE

When you look at a 192kHz A-D conversion system like the digital board in Focusrite's ISA One Digital, you're looking at what is effectively a fourth-generation design, where all the factors we discuss here have been tweaked, developed, revised and improved to take advantage of advances in converter silicon design. Gone are the days when 'cost-effective' meant 'limited quality' analogue I/O: the ISA One Digital at least equals the performance of available standard interfaces, and its on-board conversion makes the unit self-contained and means that it does not occupy any valuable line inputs on an audio interface. Instead it can go straight into your system via AES/EBU or S/PDIF, thus bypassing the entire standard interface path.  Further research and development went into the design of the optional 192kHz A-D card for the ISA828, which combines eight ISA series transformer-based mic preamps in a single 2U unit. This used a new converter part and a specialised very low noise, high current amplifier for the front end of the converter. Once again, the key to a good design was component choice, including the selection of low-noise components with high dynamic range and low distortion; and careful board layout. By taking a more sophisticated, more cost-effective approach to this multichannel product, it was possible to reduce the chip count on the digital side of the board from around 20 to just four chips. The result is a conversion system delivering a level of performance that sets the standard for the marketplace as a whole.

## THE MEANING OF R&D

Of course, it's always possible to do better, even with existing components. Running conversion chips in parallel can improve performance, for example, but at a significant additional cost. The challenge is to push back the boundaries of performance without unwarranted cost to the purchaser: there's no point in having a world-beating system that is so much more expensive than its competitors that nobody buys it. Indeed, we could characterise the "Research" part of R&D as the path to producing innovation as cost-effectively as possible. The result goes to the "Development" phase, where the aim is to produce actual products to put into people's hands. The fact that there are different acceptable price points for different market segments also means that there will be performance differences too across those segments. To an extent, you get what you pay for.

The analogue section also needs to be physically separated from the digital section, and requires judicious use of ground planes and multilayer boards. In an A-D design, low-noise amplifiers are needed to feed the input to the conversion chip itself, which also requires a very low input impedance: low impedances mean higher current, which in turn requires larger circuit board track areas, and more careful design.

## Balancing Noise And Distortion

As always, the design is a trade-off between noise and distortion. As level increases, the noise level drops, but the distortion rises as you approach 0dBFS. The challenge is to get the right balance. Low impedance sources, proper current management, and factors as small as how the tracks on the circuit board are routed are important in minimising distortion, while high amplitude helps to minimise noise.

It's always a good idea to look at the output with an FFT (Fast Fourier Transform) analyser, to see if there are any periodic functions, which might be caused, for example, by a track on the board acting as an antenna. Each component also generates its own noise, and a haphazard arrangement of components on the board can result in random components defining the noise floor. A great deal can also be learned by listening to the noise: how 'white' or broadband is it? The broader its bandwidth, the better.

## From Analogue To Digital

On the digital side, there is the question of clocking. Clocking would be easy if the clock rate didn't have to change — but of course, it does, as devices need to lock to each other. And the minute a phase-locked loop is involved, the situation gets more complex and simplicity goes out of the window. But readily available modern clocking solutions, such as the tried-and-tested Jet PLL™ system for clock recovery and reclocking, allow hardware manufacturers to focus on the analogue side of the equation. Similarly, jitter-elimination is more straightforward today, because the majority of jitter created by modern systems is random, whereas in the past it tended to be cyclic, for example.

## In Summary

As we've found, several different stages are involved in the design and development of digital conversion systems. Today, many of the old issues of digital audio have been surmounted, and yesterday's solutions to the grand challenges of the conversion process are today largely the stuff of myth and legend, and not of reality, and are of limited relevance. Today the task is to push back the boundaries of dynamic range, striving towards the 144 dB theoretical maximum for a 24-bit system. This requires the regular advances in the silicon of conversion chips to be matched by ever-improving componentry, board layout and analogue circuit design.

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