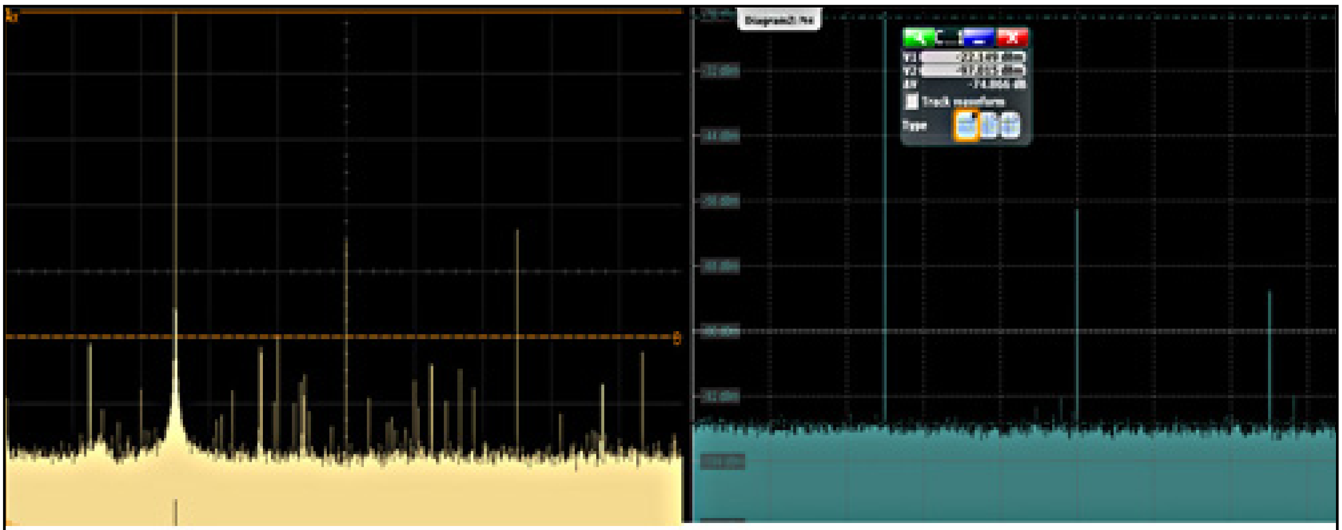
# Real-time Scope Uses Single ADC to Reduce Noise and Boost Dynamic Range

Mike Schnecker, Rohde & Schwarz, www.rohde-schwarz.us

Perched as it is at the front end of the oscilloscope, the analog-to-digital converter (ADC) is arguably the key component in determining how well the processing elements behind it can perform. Not surprisingly, scope manufacturers closely guard their ADC “secret sauce”. However, they all have one thing in common: ADCs that are built up from multiple interleaved ADCs that together comprise the overall device. At least that was true until the recent development of an oscilloscope that defies convention by only using one ADC to significantly reduce distortion and provide a high voltage per division setting, while enabling a higher effective number of bits (ENOB) value.

Modern “real-time” oscilloscopes with high sampling rates employ ADCs that are constructed from five, eight, or even hundreds of lower-speed converters that are interleaved in parallel. They are connected, or interleaved, within the device with the goal of ensuring that their electrical performance will vary as little as possible. While ideally each one would have identical performance characteristics, fabrication variances make this impossible since each converter has its own noise, phase, and frequency response characteristics. In addition, interleave timing is critical when the measured intervals are measured in tens of picoseconds. The sampling clock distributed to each converter must also have extraordinarily precise phase characteristics over the device’s entire frequency range, which is not a trivial challenge.



Frequency spectrum of a 100-MHz sine wave sampled at 10 Gs/s using interleaved A/D converters (left) with a single A/D converter (right).

Timing of each “subconverter” varies to some degree with respect to the others, so if five converters are interleaved there will be five slightly different sampling clocks, the results of which show up in the frequency domain as components at the fundamental frequency. These frequency components are typically 40 dB or 50 dB below full-scale (but nevertheless still clearly visible) and appear periodically so they cannot be averaged out as is possible with noise. This is visible in Figure 1, where the spectrum of a 100-MHz sine wave sampled at 10 Gs/s using interleaved ADCs converters is shown at left and with a single A/D converter at right.

These frequency components are caused either by timing, mismatched amplitudes, or both. Since they exist in both the frequency and time domains, they can appear like noise because of the many harmonics at different frequencies that together look like a random signal over time. However, over longer periods they begin exhibit periodic behavior. This is why some scope manufacturers use large numbers of converters; together they produce results that look like noise, which can be identified and be mitigated to some. However, the broadband data signal input into an oscilloscope mixes with the spurious content from these converters, which produces additional spurious content. The overall result is a serious ADC and scope design problem.

The overall noise level of the scope -- that is noise plus distortion -- limits the number of effective bits that can be derived from the ADC. While noise can be dealt with using traditional RF and microwave design techniques such as reducing clock phase noise and the thermal noise of the amplifiers the biggest problem remains the issues caused by interleaving -- and the only way to effectively remove them is to use a single ADC.

This is why Rohde & Schwarz chose to use a single ADC in the R&S RTO Series scopes, and they're the only such instruments in which the approach is used at high sampling rates. The device is a single flash converter with 8 bits of resolution that samples at 10 Gs/s, and eliminates interleaving problems because there are no subconverters to interleave. The ADC achieves an impressive effective number of bits (ENOB) of 7 (out of eight).

The result is a decrease in system noise floor by about 6 dB This improves signal-to-noise ratio and dynamic range so very small voltages can be discerned because the portion of the measurement consumed by system noise is significantly reduced. In addition, frequency domain measurements such as channel power, total harmonic distortion, and adjacent channel power can be more accurately determined because the spectrum is not cluttered by scope-generated noise.

This performance is exploited by a custom ASIC developed by the company that allows the speed at which the instrument can proceed from raw integer ADC samples to a measured waveform to be extremely fast, which is not typical of broadband, high-speed oscilloscopes. With 40 million sample waveforms, for example, a typical oscilloscope might require several minutes for acquisition to complete while the R&S RTO performs this operation in fractions of a second.