Compensation of sampling oscilloscope trigger jitter by an In-phase and quadrature referencing technique

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Abstract

An improved time-referencing technique, realised using commercial microwave components, has been used to improve the measurement jitter performance of a sampling oscilloscope. The limiting residual rms jitter is approximately 185 fs. The measured peak-to-peak jitter of a transition of a 10 Gb/s data stream was reduced from 7.9 ps to 3.8 ps. A 60 GHz RF signal was measured simultaneously with a 10 GHz reference signal.

Introduction

Measurements of waveforms and data on a sampling oscilloscope, or on a real-time digital oscilloscope, suffer from an uncertainty in time between the trigger and measurement events, known as measurement jitter[1]. If the measured signal is noisy then averaging is commonly used to improve the results. However, the resulting average will be convolution of the jitter probability density distribution (PDF) and the underlying waveform[2].[diagram] In many cases, this additional contribution may be small but for high-bandwidth sampling oscilloscopes this can be a significant effect. Previously, a deconvolution process has been used to remove the effects of measurement jitter[3,4]. The jitter PDF is assumed to be Gaussian and is calculated using the statistical properties of the jitter.

Jitter is also an important parameter for data communications systems as this is one of the mechanisms that can lead to errors. For datacommunication applications, the typical error-level target is $1:10^{-12}$, which can be difficult to verify directly even at data rates of 10 Gb/s. In case of data signals, jitter is the time uncertainty between the clock and the data channels. A phase-locked oscillator is often used to recover the clock signal from the data signal and systematic phase variations can arise due to the pattern of the data. In this case, the total measured jitter will be the combination of data-dependent-jitter (DDJ) and random jitter (RJ) in addition to any jitter contribution added by the measurement system. This is often modelled by a 'dual-Dirac' approximation[5,6]. The signals are often viewed on a sampling oscilloscope as an 'eye' diagram and so the deconvolution techniques used to enhance waveform measurements cannot be applied.

If data-jitter is to be accurately quantified to qualify components, then it is important to minimise the additional contribution due to measurement jitter. In this paper, we present a technique that uses the clock signal to provide a synchronised reference to correct and reduce the additional measurement jitter introduced by a sampling oscilloscope.

In this paper, the underlying concept of In-phase/Quadrature referencing is outlined. measurement examples of jitter reduction in optical datacommunications and harmonically related triggering to reduce measurement jitter are shown.

Principle of operation

The time-jitter in a sampling oscilloscope can be modelled as two random variable contributions,

$$\xi_{tot} = \xi_{trig} + \xi_{sampler}$$

where the random jitter in the trigger (ξ_{trig}) is common to all channels and each sampling gate will have an associated jitter ($\xi_{sampler}$). If $\xi_{trig} >> \xi_{sampler}$, then the overall measurement jitter can be significantly reduced by providing a reference signal on a separate channel.

If two sinusoidal signals, nominally at quadrature and with approximately the same amplitude, are measured on a sampling oscilloscope using the same trigger event then the exact point within the cycle, and hence the sample time, can be determined. This information can then be used to determine the timing of any waveforms measured using other instrument channels. The accuracy of the correction will be limited by the jitter associated with each sampling gate ($\xi_{sampler}$) and noise contributions from each sampling gate. In the example (Figure 1), trigger jitter (2 ps) and sampler jitter (0.2 ps) has been added to each of the traces.

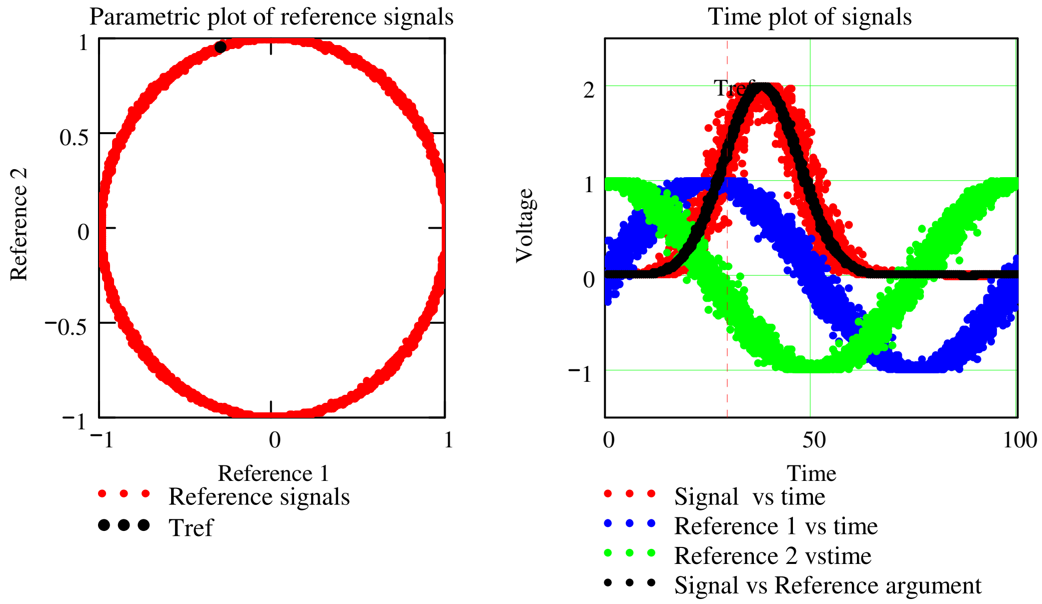


Figure 1 Parametric relationship between the reference signals uniquely defines time of measurement.

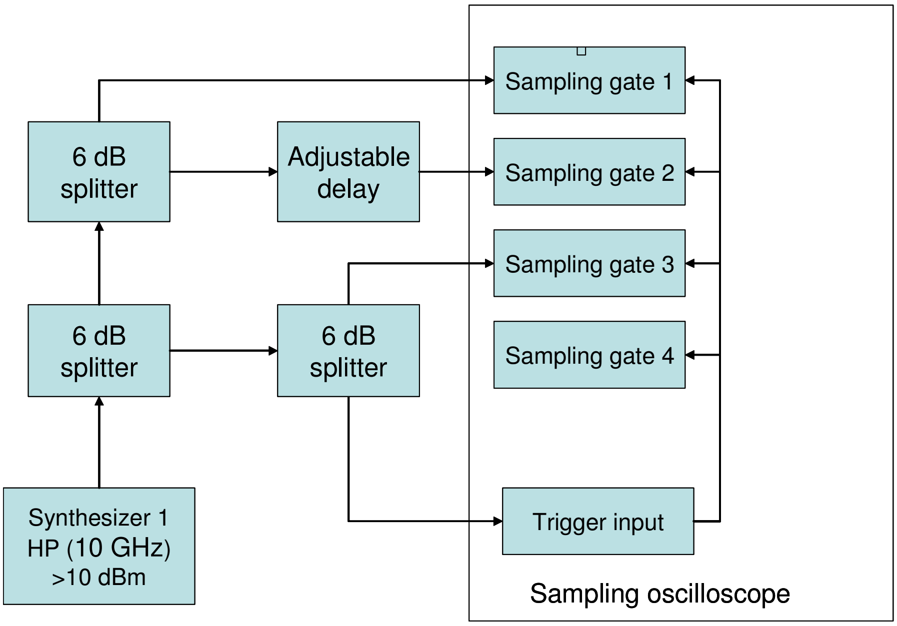
Given that the system is imperfect, the signal amplitudes from the two channels will probably not be exactly equal, nor will they be exactly at quadrature. In practice, the parametric plot (Figure 1) will describe an ellipse and may not be centred on the origin. The ellipse parameters must be determined and a series of mappings are required to transform the ellipse to the unit circle. Starting with the raw data, these are:

1. Translation to x, y origin
2. Rotation to align the ellipse major/minor axes to the x /y axes
3. Scaling x/y to unity (Unit circle mapping)
4. Inverse rotation, so that the time reference is maintained
5. Optimisation of transform parameters
6. Determine argument from the corrected data

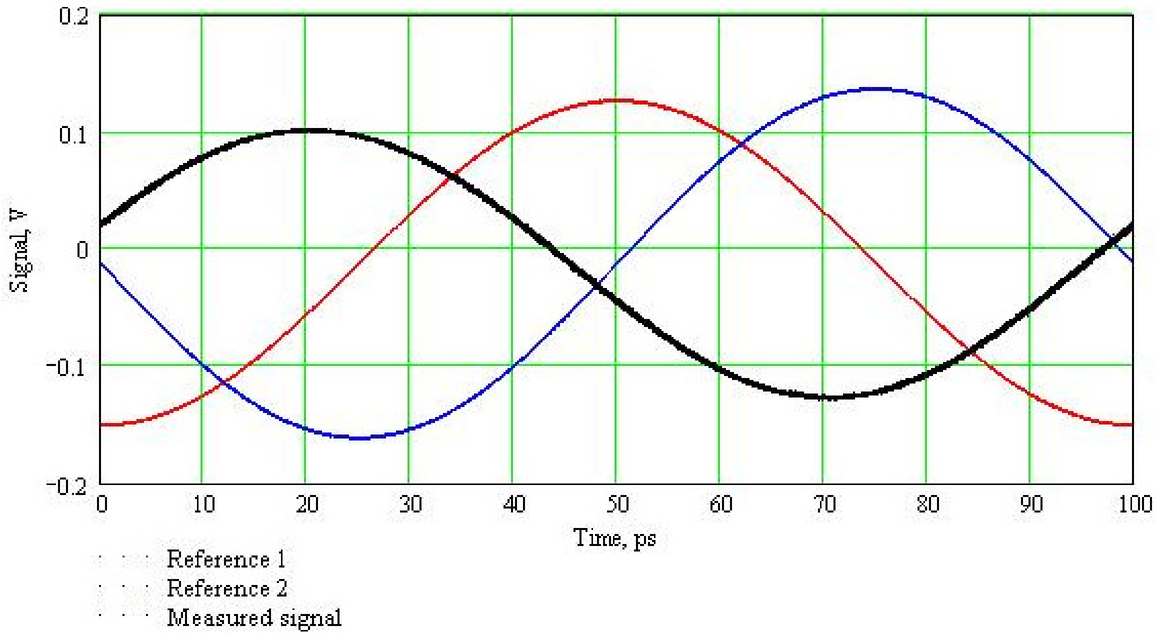
This analysis assumes that the signals are pure sinewaves. To achieve this, the reference sinusoidal signals must be filtered to remove any harmonic content. This is particularly important if the signal is derived from a digital clock. A high quality bandpass filter is ideal for this task. It is important to ensure that the passband of the filter is sufficient to meet the jitter specifications[7]

Evaluation of limits

Each channel will measure a noise component in addition to the individual sampler jitter and because this contribution is uncorrelated, it will contribute to the residual jitter.



An estimate of the residual noise and jitter can be made by applying the reference signal to the measurement channel. The residual jitter can be determined from the jitter and noise components in the corrected trace. A 10 GHz sine wave has been applied to three sampler channels. The error in the unit-circle fit of the reference data is 0.3%, giving an estimated noise contribution to the jitter of approximately 48 fs. The corrected results show residual noise and jitter components, which have been estimated to be 1.87 mV rms and 185 fs rms respectively.



Data Measurement

An optically retimed data-stream (Appendix VII of Reference 7) has been used to demonstrate the measurement approach[8]. The optical retiming significantly reduces the jitter arising within the pattern generator. A single transition within a Pseudo-Random Bit Sequence (PRBS) data sequence of 2^{15}-1 bits has been analysed to determine the peak-to-peak jitter using the timebase alone and using the reference signals to minimise the jitter contributed by the sampling oscilloscope.

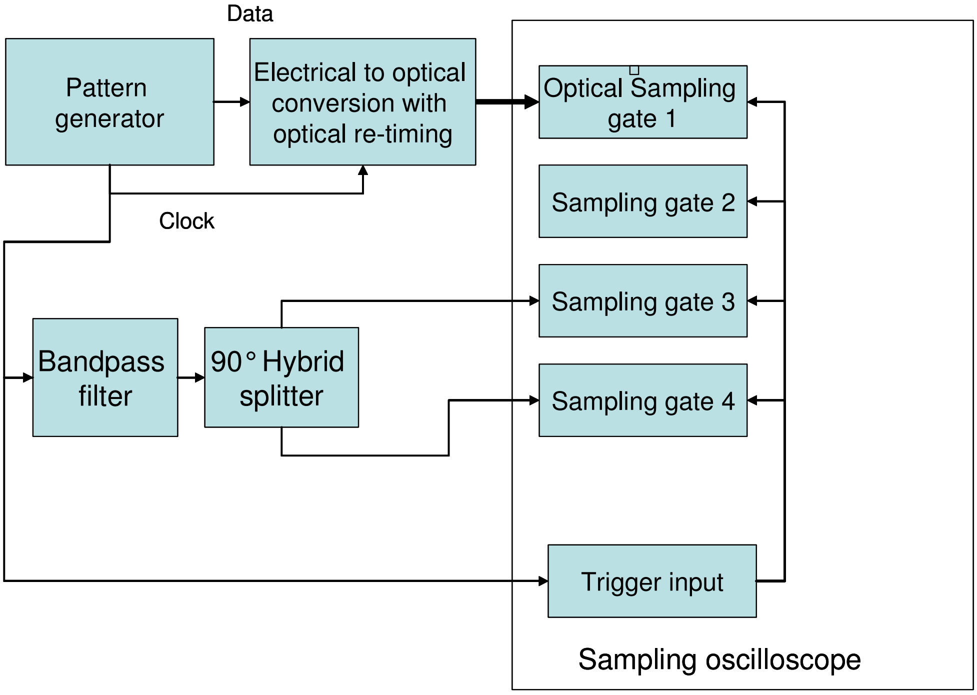
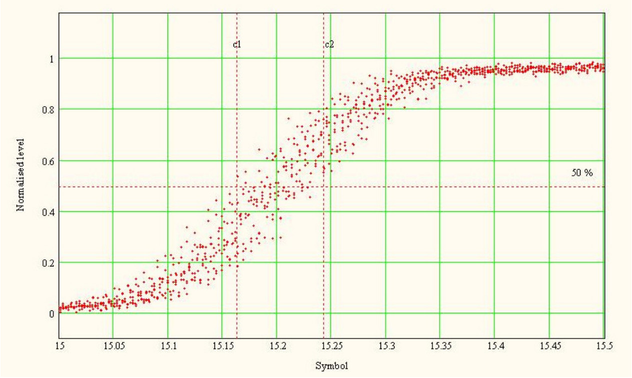


Figure 2 Measurement system used for the In-phase/Quadrature (IQ) correction of the data signals

The clock signal is filtered using a 100 MHz bandpass filter, centred at the clock frequency (9953 MHz), to remove harmonics. The filtered clock signal is divided into two equal amplitude components using either a 0 degree – 90 degree hybrid splitter or a normal splitter and delay paths that differ by a quarter of a clock period. In this case, a variable delay was used. The data waveform and two reference waveforms are simultaneously measured for all the data symbols. The time axis is reconstructed in terms of the sine and cosine components, determined from the two reference waveforms, compensating for timebase linearity and trace-to-trace pattern triggering nonlinearity.

The time-jitter in a sampling oscilloscope is much higher between the trigger input and the sampler than the time-jitter between individual samplers. If this technique is used for single trace acquisitions, the instrumentation trigger jitter can be significantly reduced as shown in Figure 3 and Figure 4.



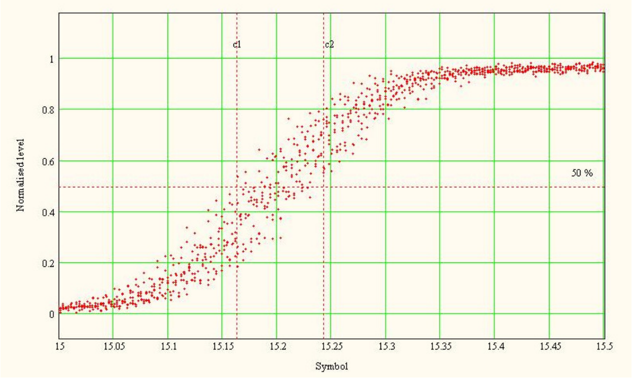


Figure 3 Rising edge without timebase jitter compensation 79 mUI p-p

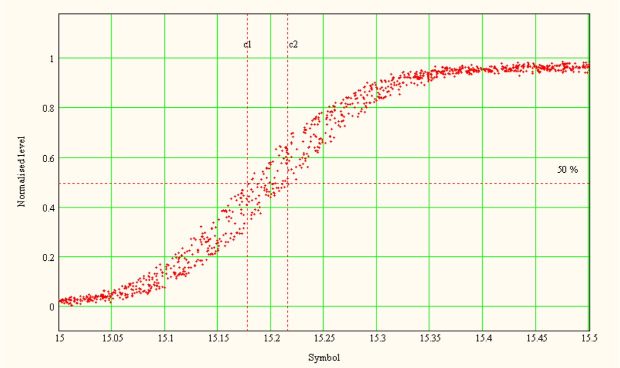


Figure 4 Rising edge with timebase jitter compensation 38 mUI p-p

If the system performance is monitored as an eye diagram, then it is important to minimise the jitter contribution introduced by the sampler. The example shown in Figure 5, shows the improvement that can be observed in a 2^{15}-1 PRBS signal by correcting for the sampling oscilloscope trigger jitter.

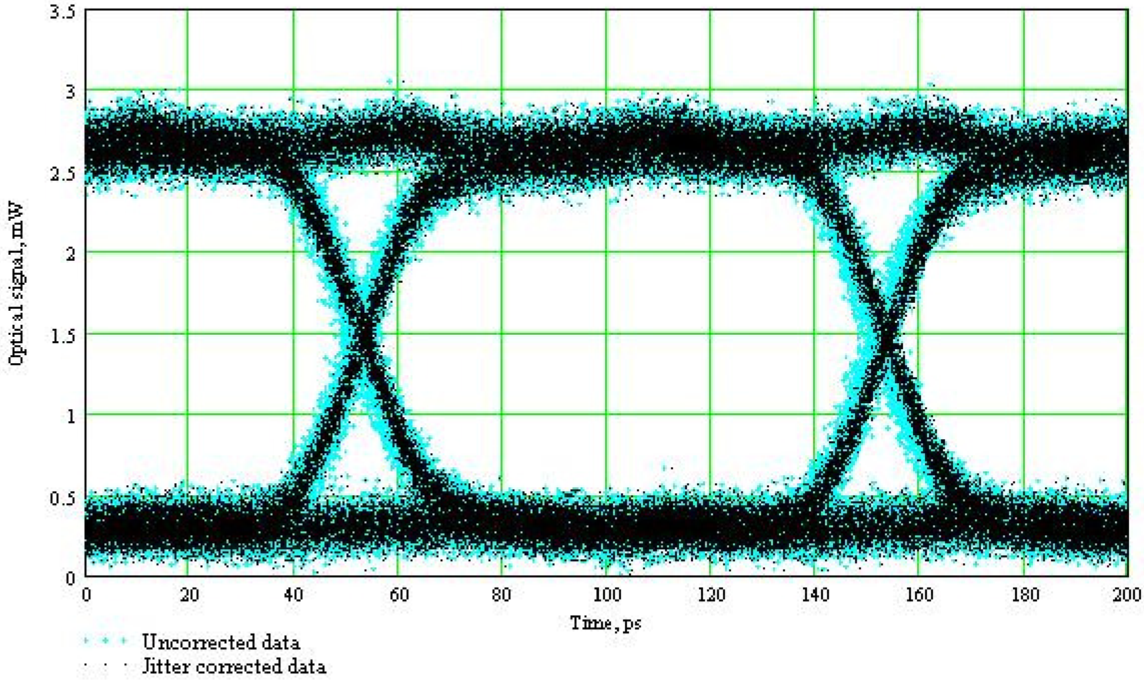


Figure 5 Eye diagram of 2^{15}-1 PRBS signal

RF Application

This technique can be applied in a wide variety of RF applications. For example, the group-delay response of optical reference receivers can be measured by a frequency-domain technique using integrated-optic modulators[9]. This technique uses the property that the Mach-Zehnder integrated-optic modulator can simultaneously generate fundamental (1f) and second-harmonic (2f) optical intensity signal components that have a mathematically defined phase relationship. Jitter between the trigger and RF signals will not affect the relative phase of the fundamental and second-harmonic signals. However, at high frequencies (2f > 50 GHz), the lower RF power available from the synthesizer and the trigger jitter significantly reduce the visibility of the high frequency signal components, increasing the required averaging time. In the original scheme, a low-frequency trigger was used (190 MHz to 210 MHz). If instead, a higher frequency synthesiser were used with a broadband 90° hybrid, then it should be possible to reduce the jitter in the result.

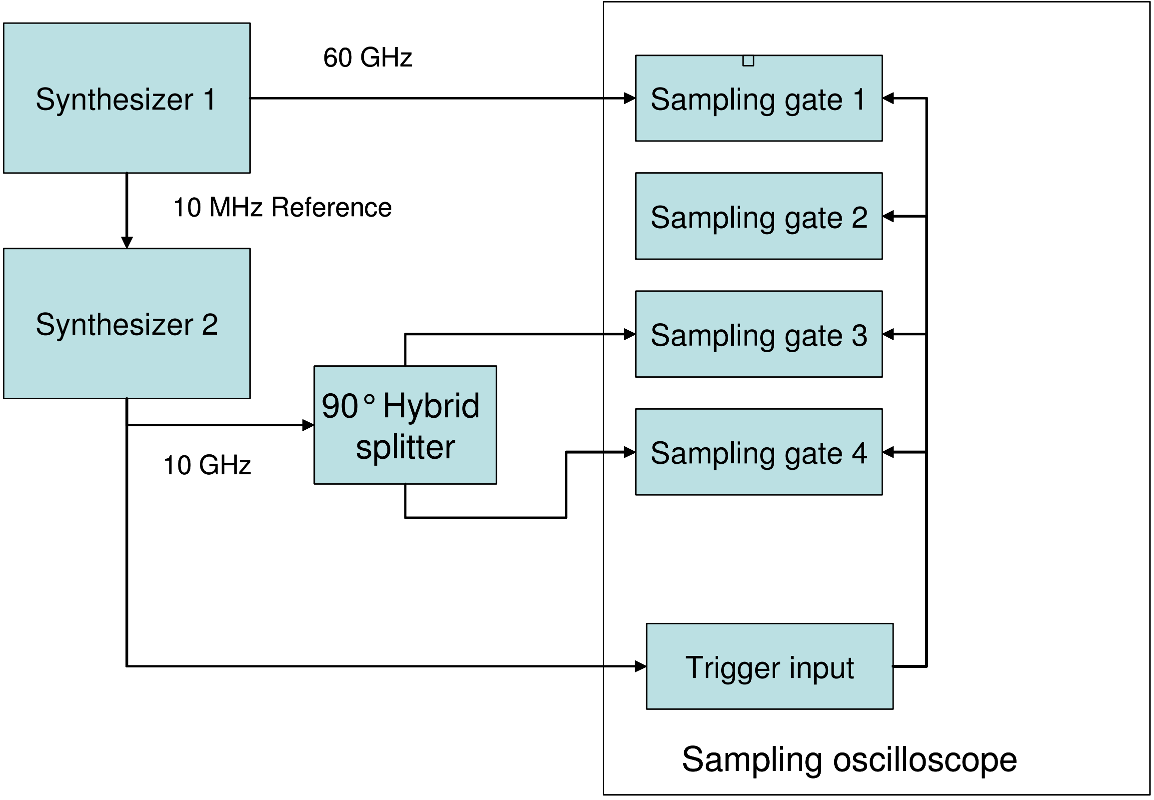


Figure 6 Experimental layout for jitter correction of harmonically-related RF signals

Two synthesizers, using a common reference oscillator, were used to provide the measurement signal (60 GHz) and an IQ reference signal at 10 GHz. The results show that the trigger jitter significantly reduces the averages signal and the jitter correction technique recovers the underlying signal. The residual jitter in the result is approximately 185 fs.

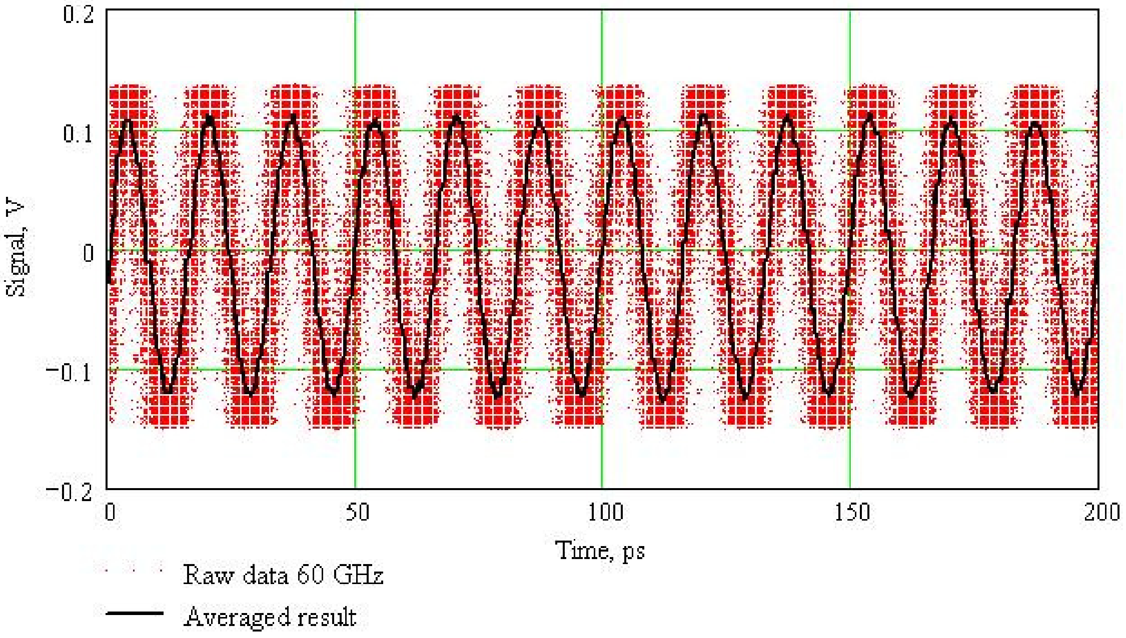


Figure 7 Jitter and mean signals at 60 GHz

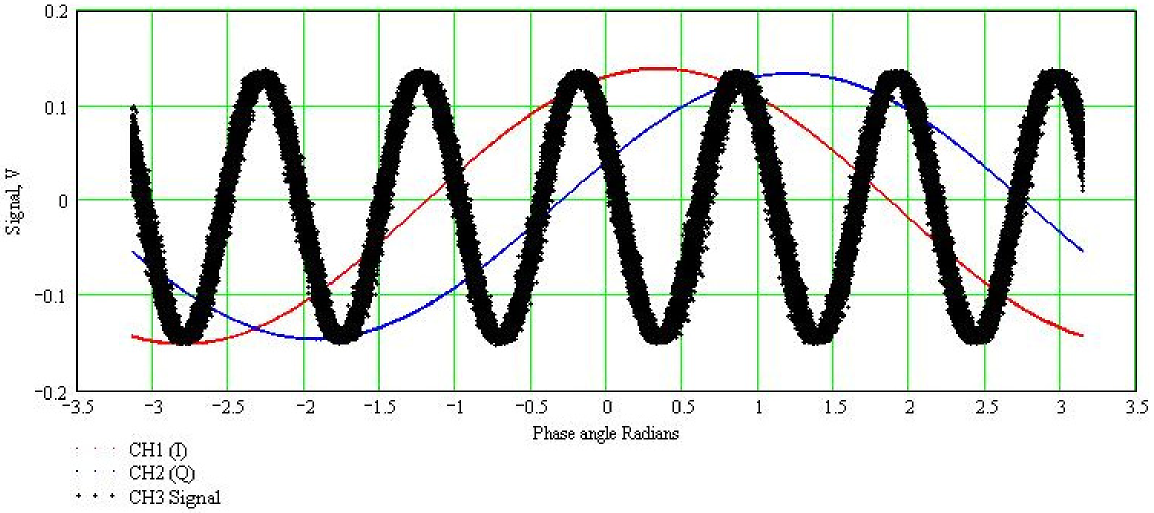


Figure 8 Jitter corrected 60 GHz signal

Discussion

The measurement technique presented here can be used to improve the jitter performance of commercial sampling oscilloscopes. This approach requires access to two additional sampling oscilloscope channels and can be realised using readily available RF components. A disadvantage of the method is that the results require additional processing and that the results will no longer be equally spaced in time.

In the examples shown here, an 8 – 12.4 GHz 90° hybrid splitter was used. With this approach, the possible frequency range of the IQ signals is limited only by the performance of the sampler an RF components.

Certain manufacturers' instrumentation may include similar systems, realised in hardware. These precision timebase systems may be designed to operate at specific, telecommunication related clock frequencies. Where these systems are present there is no significant improvement to be gained by adopting this technique.

Acknowledgements

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