

VECTOR MEASUREMENT OF MODULATED RF SIGNALS BY AN IN-PHASE AND QUADRATURE REFERENCING TECHNIQUE

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Abstract

Vector measurements of modulated RF signals are demonstrated using a sampling oscilloscope with in-phase and quadrature referencing. This technique provides an alternative technique to real-time digitising oscilloscopes or real-time spectrum analysers and can be used at higher RF frequencies than these other methods.

Introduction

In this paper, we describe a new technique using a sampling oscilloscope to measure the vector response of a repetitive, modulated RF signal. Typically, modulated RF signals are measured using a high-bandwidth digital oscilloscope or a real-time spectrum analyser. Sampling oscilloscopes operate to significantly higher frequencies than real-time oscilloscopes and have previously been used to characterise pulsed RF signals using a statistical approach [1] that requires a large number of samples to achieve low uncertainties.

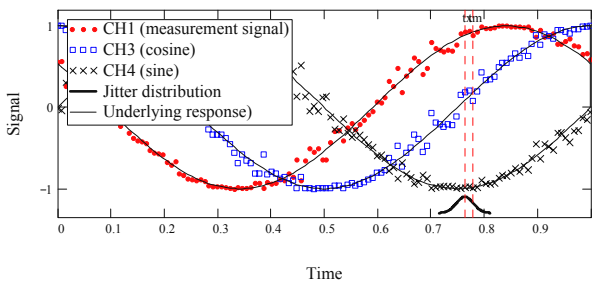


Figure 1 In-phase and quadrature (IQ) reference signals, applied to other instrument channels (CH3, CH4), can be used to compensate for measurement jitter of a third waveform (CH1).

Principle of operation

The time-uncertainty (jitter) between the trigger and a sampler is much less than the jitter between individual samplers. Consequently, in certain designs of multi-channel instrument, the other channels can be used to provide accurate time-reference information. 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. The accuracy of the correction will be limited by the jitter associated with each sampling gate and noise contributions from each sampling gate (see Figure 1). This technique has previously been used to significantly reduce measurement jitter when characterising digital signals [2].

In practice, the in-phase and quadrature signals will have slightly different amplitudes; they will not be exactly orthogonal and may have DC offsets. A parametric plot of the two reference channels will typically show an ellipse that is not centred on the origin. These impairments can be overcome by applying a sequence of simple transforms that map the results to a unit circle where the exact time of measurement can be determined from the argument of the result.

Measurement system

Two frequency-locked synthesisers are used as the sources. The first of these is used to provide the reference signals and the second provides the modulated signal under investigation (see Figure 2). The sampling oscilloscope is triggered by the pulse modulation signal. Ideally, an attenuator should be included in the lines between the synthesisers and the sampling oscilloscope to improve the match performance.

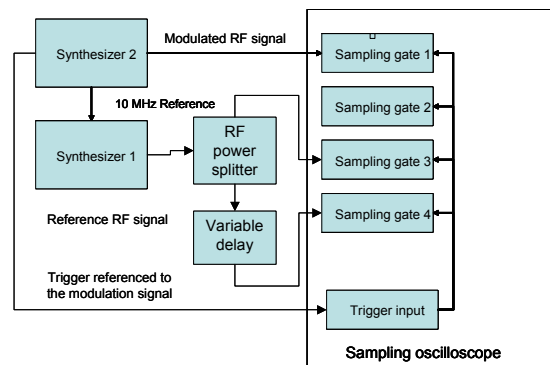


Figure 2 Measurement layout for vector measurement of RF signals.

Filtering and residual jitter

The pulse-envelope trigger-signal has a slow risetime, giving rise to jitter that is significant on the timescale of the RF carrier. In successive measurements, the jittered trigger randomly samples the RF signals at different points within the cycle. To obtain a good estimate of the magnitude and phase of the measurement signal, the peak-to-peak jitter should exceed a single RF cycle. If this is not the case then the results from several adjacent time-points must be averaged. The net effect of the averaging is to apply a known low-pass filter to the envelope results.

RF pulse example

Both synthesisers were operated at 12 GHz with an RF pulse modulation of 100 ns duration and 500 ns period and 100 samples were taken at each time-point. A six point moving average has been used because the jitter in the measurements at each time-point is less than the

period of the RF signal (Figure 3). At each six time-point average, the fundamental Fourier component is calculated by a numerical integration method

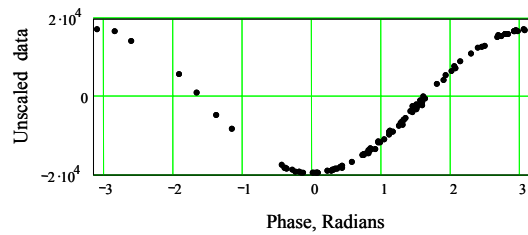


Figure 3 Trigger jitter at the measurement point is less than the period of the RF carrier

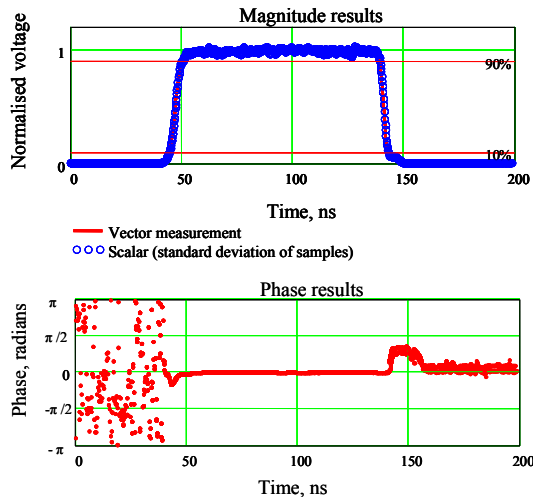


Figure 4 Magnitude and phase of the RF envelope measured using the IQ referencing technique and magnitude response determined from the standard deviation of the samples at each time-point.

In order to provide a comparison, the magnitude response has also been calculated by a statistical (PDF) approach [1]. The pulse parameter results [3] show good agreement (Figure 4 and Table 1). The phase changes in the RF signal during the on-off transitions are clearly visible.

Table 1. RF Pulse envelope transition durations, calculated in accordance with IEEE Std. 181 [3]

RF Pulse envelope parameters	Vector IQ	PDF	
Transition Duration, positive	5.8	5.7	ns
Transition Duration, negative	3.7	3.6	ns
Pulse Duration	93.8	93.8	ns

Communications applications

This technique can be used to recover in-phase (I) and quadrature (Q) signals for simple repetitive patterns in communications applications (see Figure 5). The key restriction is that the data pattern must be chosen so that the phase of the carrier is the same for each trigger event. This approach has been successfully used with simple patterns in 4QAM, 16QAM and $\pi/4$ -DQPSK formats.

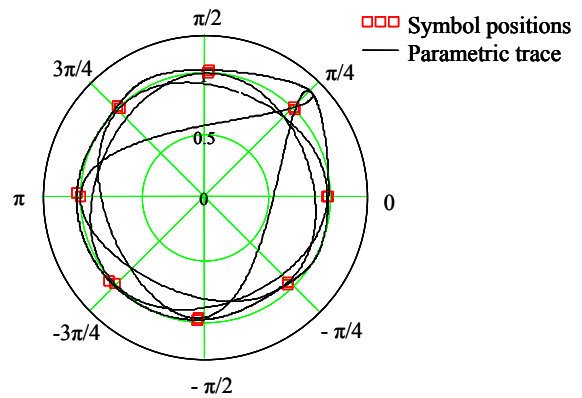


Figure 5 Constellation diagram for a $\pi/4$ -DQPSK signal at 1.9 GHz comprising 16 '1's and 16 '0's with a Root Raised-Cosine filter ($\alpha=0.35$) applied.

Summary

We have outlined a new vector measurement technique, using sampling oscilloscopes, to characterise repetitive RF signals. This method can be used at high frequencies and offers an alternative approach to real-time oscilloscopes and real-time spectrum analysers. The disadvantage of this technique is that a repetitive signal is required, limiting its usefulness to some of the simpler communications modulation schemes.

Acknowledgements

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References

- [1] D A Humphreys and J Miall, 'Traceable RF Peak Power Measurements for Mobile Communications', IEEE Trans. Instrum. Meas., vol. 54, no. 2, April 2005, pp. 680-683.
- [2] D A Humphreys and F Bernard, 'Compensation of sampling oscilloscope trigger jitter by an in-phase and quadrature referencing technique', ARMMS Meeting 18 and 19 April 2005, Abingdon, Oxfordshire, UK.
- [3] *IEEE Standard on Transitions, Pulses, and Related Waveforms*, IEEE Standard 181, 2003.