Phase Calibration of Oscilloscopes at Low Frequencies

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***Abstract* — This paper describes how to calibrate phase response of oscilloscopes, especially at low frequencies from 10 MHz to 1 GHz. The method uses the phase response of a standard mixer calibrated by three-mixer method as the reference phase. We describe basic principles and show results obtained using a balanced mixer and a real-time oscilloscope (1 GHz BW).**

I. Introduction

Oscilloscopes are often used to measure time domain signals. Various calibration methods are used to characterize the dynamic time domain performance of oscilloscopes. Electro-optic sampling (EOS) method can be used to determine the complex transfer function (equivalent to the impulse response in the time domain) of oscilloscopes. The complex transfer function thus obtained may be used to correct the shape of any waveforms by de-convolving the measured signal [1]. The EOS method works well for measurements requiring high bandwidth, 110 GHz or more, but it has degraded uncertainty below several hundred MHz due to the maximum time interval the system is capable of measuring. Furthermore, it is difficult to obtain accurate absolute scaling for the voltage pulse generated by the PD [2]. As an alternative, especially in the low frequency, swept-sine (frequency-domain) method is usually used to calibrate the magnitude of transfer functions, which is traceable to a RF power standard. However, since the swept-sine calibration does not give phase information, the method does not characterize a scope response completely. In this paper, we describe a procedure for calibrating the phase response of oscilloscopes to make up for a shortcoming in the swept-sine method.

II. Phase Calibration Method

Fig. 1 shows a setup of our method. One signal generator produces the RF signal (at a multiples of 10 MHz), the other one generates the LO signal. RF and LO signal are applied to the ch-1 and the ch-3 input of the oscilloscope, respectively. A signal from the IF port of mixer is band-pass filtered, and connected to the ch-2 input of the oscilloscope. The frequency of IF is 10 MHz. A clock distributer synchronizes all equipment. It is also assumed that the four channels of the oscilloscope are fully synchronized to the 10 MHz clock. All four channels are sampled and saved for post processing, where the phases between channels are calculated.

Mixer phase response evaluated with Vector Network Analyzer (VNA) is used as a phase standard in this method. Reference mixers are characterized with the "three-mixer method." This method is based on measurements of the product of signals, up-converted by one mixer and down-converted by another. These measurements are fairly straightforward, as the frequencies of the incident and reflected signal at the mixer port are the same. When three mixers are measured in various combinations, it is possible to uniquely determine the transfer functions of all three mixers if one of three mixers is reciprocal [3]. Three-mixer method does not need the standard mixer to establish traceability chains.

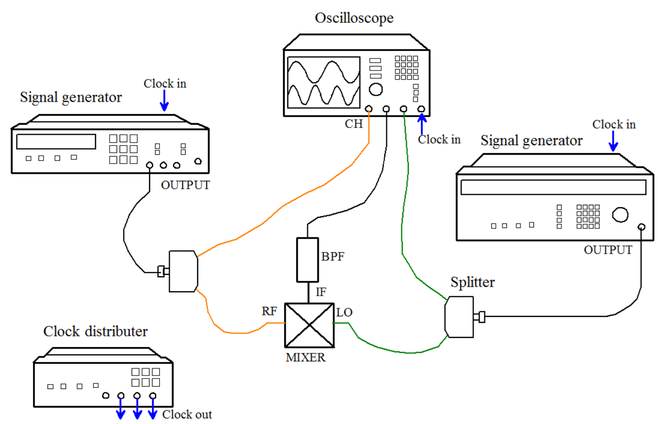

Fig. 1. A setup for calibrating the phase response of an oscilloscope.

The phase response of the mixer is obtained using (1) as in [4].

$$\varphi_{21} = \frac{\varphi_2+\varphi_3-\varphi_1-\varphi_{21\_IF}}{2} \qquad (1)$$

$\varphi_1, \varphi_2, \varphi_3$, and φ_{21IF} can be measured with a VNA or an oscilloscope. In the computation of the square root function for a phase response, phase unwrapping is necessary before the square root is taken. At the next section, we describe the procedure used to obtain the measurement results.

III. Results

We used a four-channel real-time oscilloscope having nominal bandwidth of 1 GHz and the setup shown in Fig. 1. A commercial 10-2000 MHz mixer was used as the reference mixer. We operated the mixer in a normal mode. Fig. 2 is the traces of four channels measured during our experiment.

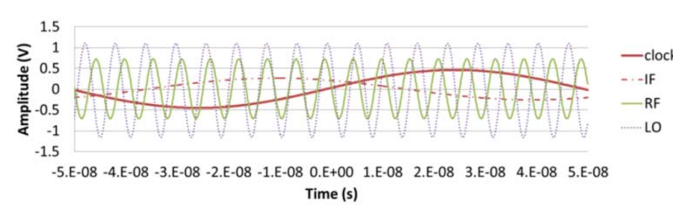

Fig. 2. Traces of signals measured on the four-channel oscilloscope.

The thick trace is a partial waveform of 10 MHz clock measured on ch-4. For the calculation of phase differences, zero crossing points of each waveform were measured. Fig. 3

is the measured results of phase difference relative to the clock. The dotted line is obtained by subtracting the phase of LO signal from the phase of RF signal. The solid line is the phase of IF signal.

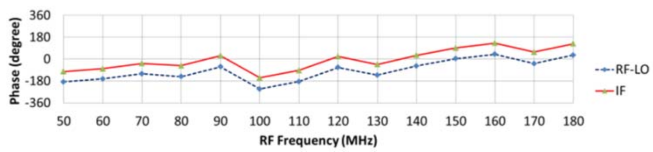

Fig. 3. Phase difference of the signal.

By subtracting the dotted line from the solid line, and then compensating it with the phase response of the mixer, phase response of the oscilloscope is obtained. Fig. 4 is a detrended phase response of the oscilloscope.

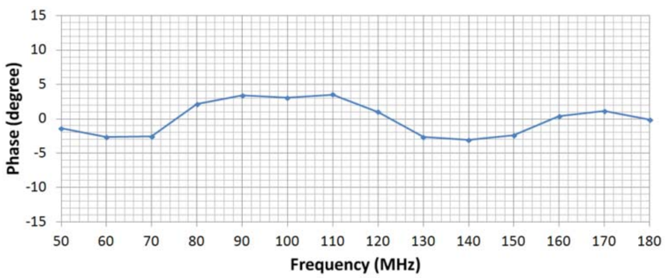

Fig. 4. Detrended phase response of the oscilloscope.

VI. CONCLUSION

The novel method to calibrate the phase response of oscilloscopes, especially at low frequencies from 10 MHz to 1 GHz, was described. The method used the phase response of a standard mixer calibrated by three-mixer method as the reference phase. The deviations of the measured results are still large. Major contribution of the deviations is due to the phase response of the reference mixer, which was calibrated by three-mixer method. To get better results, we are going to try other methods for the calibration of reference mixer and try more refined algorithms for the determination of the phase difference between oscilloscope traces. More revised results including measurement uncertainty will be presented at the Conference.

ACKNOWLEDGEMENT

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