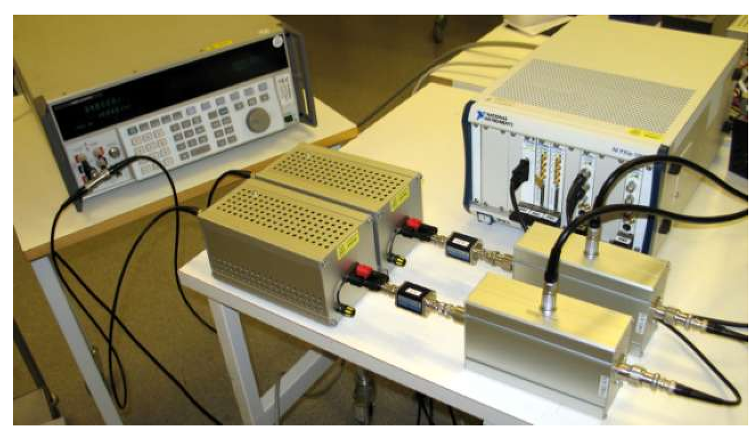
Precision measurement system for characterisation of phase displacement of voltage dividers up to 1 MHz

Tobias Bergsten, Valter Tarasso and Karl-Erik Rydler
SP Technical Research Institute of Sweden
Box 857, SE-501 15 Borås, Sweden

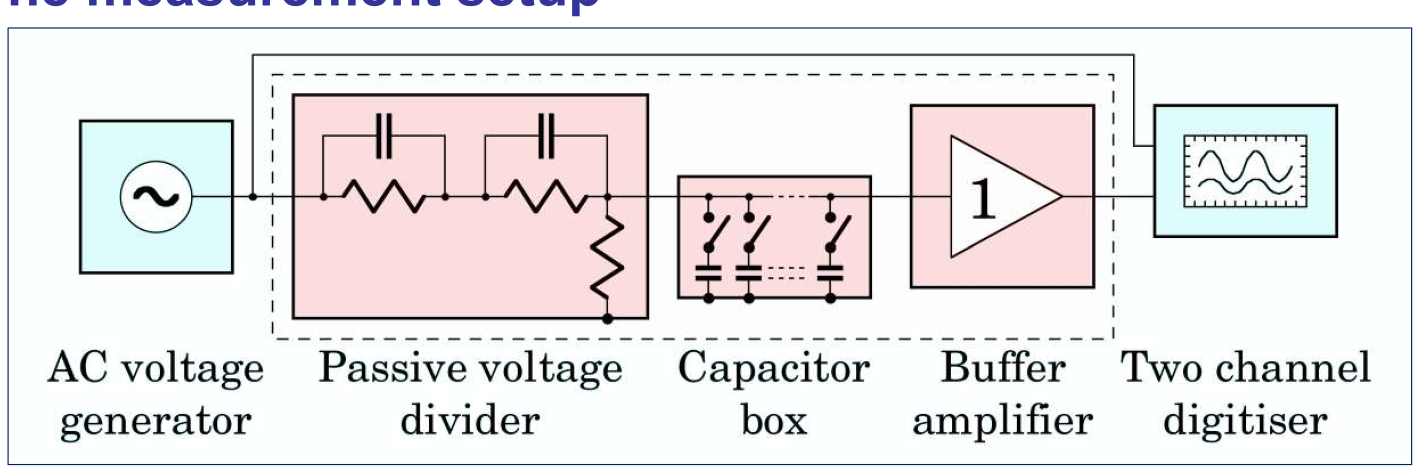
SP Technical Research Institute of Sweden

Introduction

As one part in the joint research project "Next generation of power and energy measuring techniques" of the European Metrology Research Programme, we have developed a technique to measure the phase displacement of voltage dividers at frequencies up to 1 MHz. The development of new wideband power meters requires new tools to accurately measure power at much higher frequencies than the traditional 50 Hz.



The measurement setup

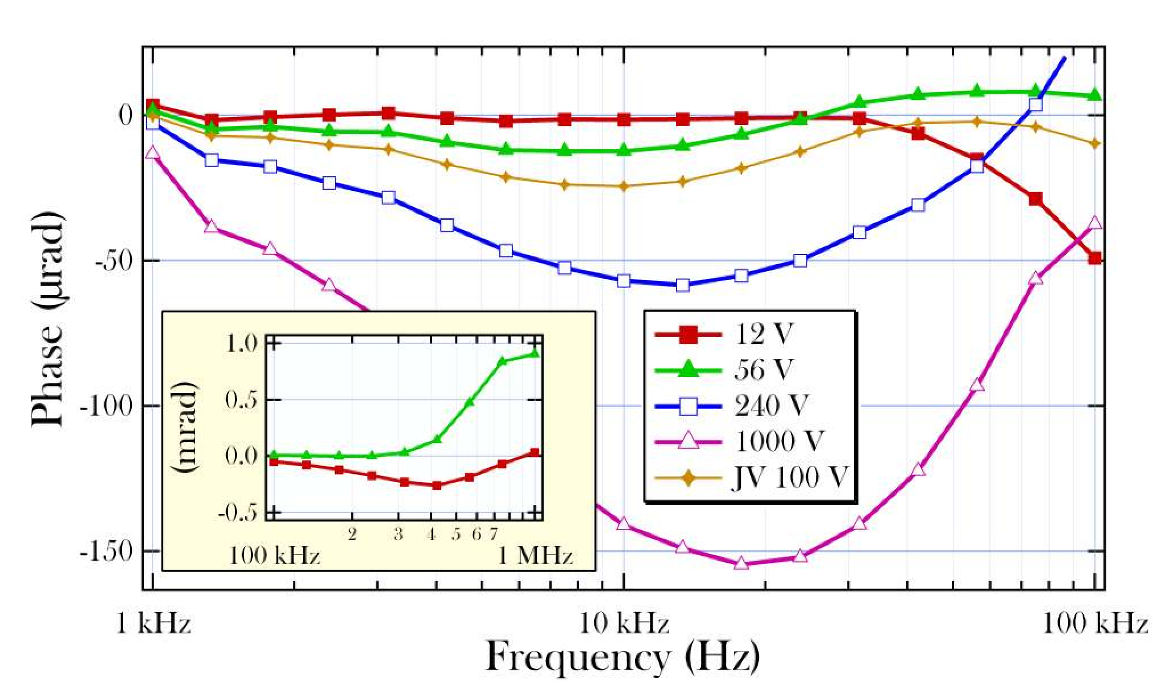


The figure above illustrates the measurement setup. The red items constitute the active voltage divider whose phase displacement is to be characterised. The digitiser samples the signal from the divider simultaneously with a reference signal (top line) and identifies the phase difference between the two signals. For low ratio dividers the reference signal is the input signal to the divider, but for higher ratio dividers the reference signal is the output of a lower ratio divider connected in parallel [1].

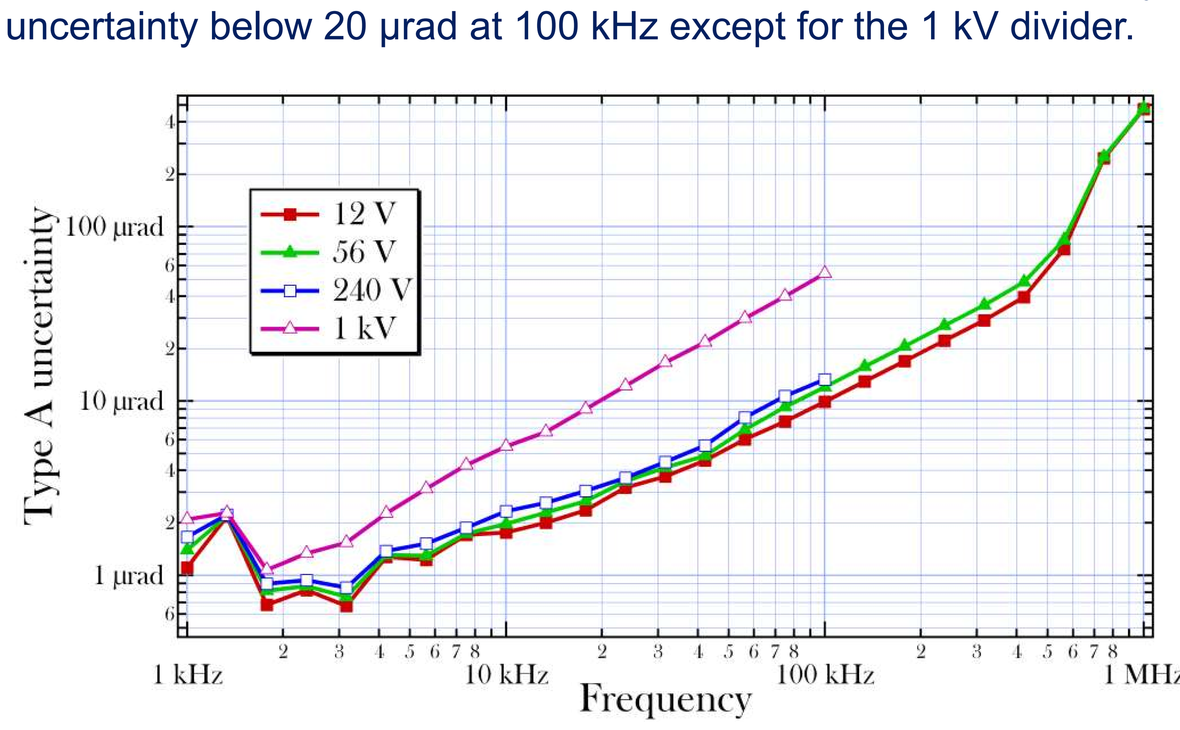
The active divider consists of a resistive divider with parallel capacitors which are adapted to the capacitive load in our digital sampling wattmeter (DSWM) system [2]. The dividers include a capacitive guarding scheme in order to minimise the phase displacement of the divider. If we connect the output of these dividers directly to the digitiser the capacitive load is not matched and the phase displacement will be considerable at higher frequencies. At higher frequencies the phase is also very sensitive to tiny changes such as bending the signal cable different ways. We therefore added a capacitor box to match the capacitive load, and a buffer amplifier, and used rigid connections between the resistive divider, capacitor box and buffer amplifier, in order to ensure a well defined phase displacement of the divider. The buffer amplifier is based on the design in [3] and has excellent performance up to 1 MHz.

Results

A typical phase measurement result is shown in the figure below. We use a series of dividers with nominal input voltages from 4 V to 1 kV (not all are shown below). A prototype divider from the Norwegian Metrology Service (JV) was also measured for comparison.



In order to find out how reproducable the measurements are we measured the full series of dividers three times, on different days. The type A uncertainty due to the variance of the three measurements is shown below. The reproducability is excellent with an uncertainty below 20 µrad at 100 kHz except for the 1 kV divider.



Identifying the phase

We use a function in the Labview software called "Extract Single Tone Information" (ESTI). This function identifies the frequency, amplitude and phase of a sampled signal using Fourier transform and an interpolation algorithm. Given two sampled signals X_i and Y_i (plus some noise and distortion), defined as

$$X_i = A_X \sin \omega t_i \qquad Y_i = A_Y \sin(\omega t_i + \theta)$$

it is possible to identify the phase difference θ using the ESTI function directly. However, if the phase difference is small the accuracy can be improved by another method. Using ESTI we identify the amplitudes A_X and A_Y of the two signals and create the normalised difference signal Z_i:

$$Z_i = X_i / A_X - Y_i / A_Y = A_Z \sin(\omega t_i + \theta_Z)$$

Where the amplitude A_Z and phase θ_Z are

$$A_Z = \sqrt{2(1-\cos\theta)} \qquad \theta_Z = -\arctan\frac{\sin\theta}{1-\cos\theta}$$

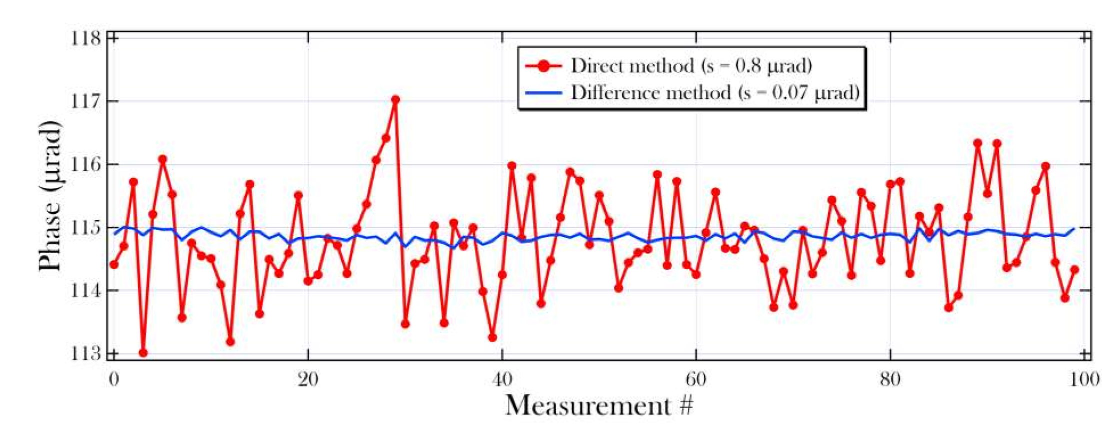
If we take the sin of the phase θ_Z we get

$$\sin\theta_Z = \frac{-\sin\theta}{\sqrt{2(1-\cos\theta)}}$$

and we can write the phase θ of A_Y as

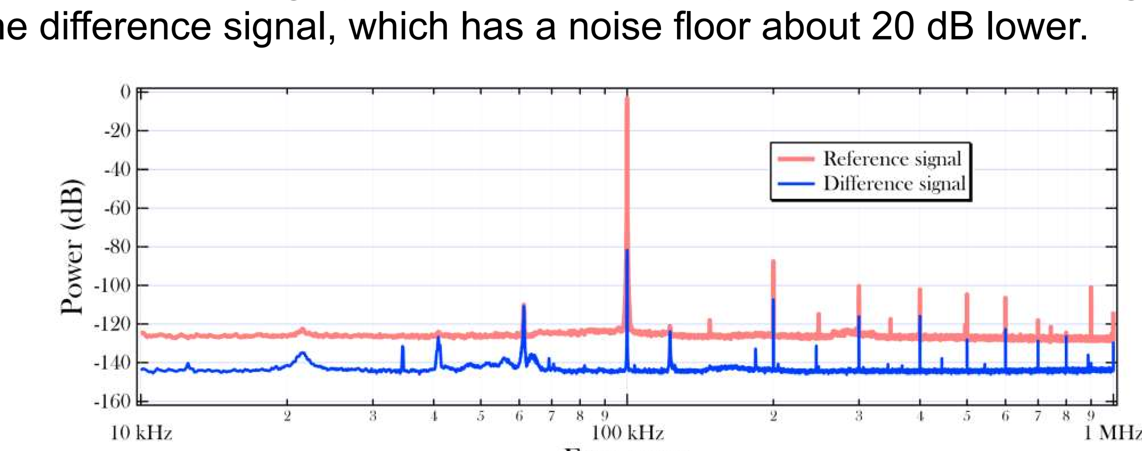
$$\theta = -\arcsin(A_Z \sin\theta_Z)$$

We can use ESTI to identify A_Z and θ_Z and calculate the phase using this formula. This method gives much lower noise compared to identifying the phases directly from A_X and A_Y as demonstrated in the figure below.



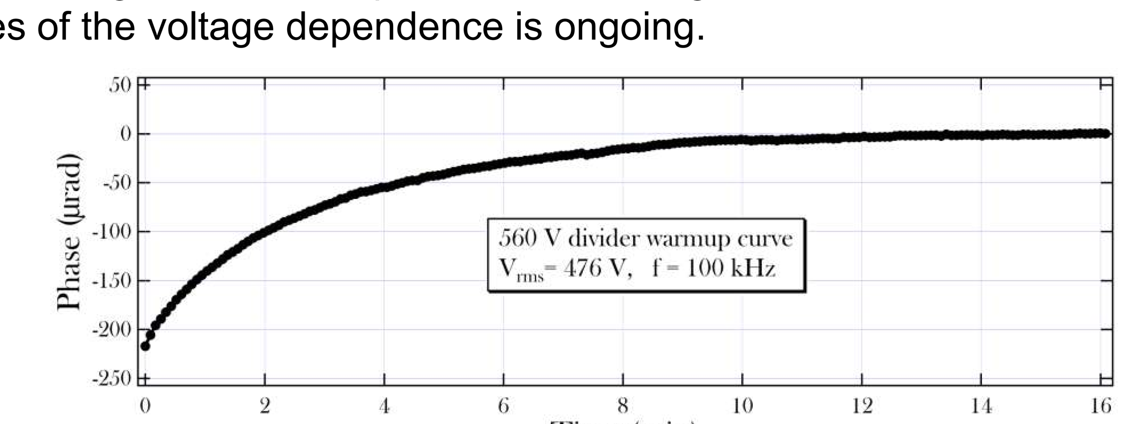
In this figure a 100 kHz signal is connected to a buffer amplifier and the phase between the output and the input signals is identified both directly from the sampled signals (red curve) and with the method described above (blue curve).

The reason for the lower noise is that subtracting the two signals removes a lot of correlated noise. The graph below shows the spectrum of the input signal (reference) and the difference signal, which has a noise floor about 20 dB lower.



Voltage dependence

The stepping procedure where lower ratio dividers provide the reference signal for higher ratio dividers introduces an additional uncertainty because the dividers are characterised near the nominal voltage of the next lower ratio divider and then used as the reference near their nominal value. The level dependence of the phase is both due to the voltage and to the ohmic heating of the resistive dividers, particularly at higher voltages. An example of the heating effect is shown in the graph below. Studies of the voltage dependence is ongoing.



Acknowledgement

This work was supported within the Swedish National Metrology Research Program and has received funding from the European Community's Seventh Framework Programme, ERA-NET Plus, under Grant Agreement No. 217257.

[1] K.-E. Rydler, S. Svensson, and V. Tarasso, "*Voltage dividers with low phase angle errors for a wideband power measuring system*," in CPEM Conference Digest 2002, pp. 382–383, 2002.

[2] S. Svensson and K.-E. Rydler, "*A measuring system for the calibration of power analyzers*," IEEE Trans. Instrum. Meas., vol. **44**, pp. 316–317, Apr 1995.

[3] I. Budovsky, A. Gibbes, and D. Arthur, "*A high frequency thermal power comparator*," IEEE Trans. Instrum. Meas., vol. **48**, pp. 427–430, Apr 1999.