Exploring the Low Frequency Performance of ThermalConverters Using Circuit Models and a Digitally Synthesized Source

N. Oldham, M. Parker, and B. Bell
Electricity Division
National Institute of Standards and Technology[1]
Gaithersburg, MD 20899

Ṡ. Avramov-Zamurovic
Weapons and Systems Department
U.S. Naval Academy
Annapolis, MD

Abstract

Low-frequency tracking errors of thermal voltage converters are described and estimated using circuit models. A digitally synthesized source is used to confirm ac-dc differences in the 0.001 Hz to 40 Hz range.

1. Introduction

A calculable digitally synthesized source (DSS) has been used as an independent method of verifying the ac-dc differences of thermal voltage converters (TVCs) below 1 kHz [1]. A DSS has also been used to probe the very low frequency (below 1 Hz) performance of TVCs [2]. This paper describes the low-frequency errors of TVCs in terms of easily-measured circuit parameters.

Most TVCs consist of a resistor, used to limit the test current to a few milliamperes, connected in series with a low-current thermoelement (TE). A TE consists of a low-resistance heater attached to a temperature sensor. The sensor is generally a thermocouple that produces a small output emf proportional to the heater temperature. The heater temperature is proportional to the input power $P = V^2/R$, where V is the rms voltage and R is the heater resistance of the TVC. If the amplitude of the test voltage is constant and its period is small compared to the time constant of the TE, the heater temperature and output emf are constant. In this operating mode, the TVC is a mean-squared voltage-to-dc voltage converter.

The TVC time constant (defined as the time required for the output emf to reach 63% of its final value) can vary from a few milliseconds, for TEs with thin film heaters, to a few seconds for those with more massive wire heaters.

Because the TE heaters are not perfectly thermally isolated, there is heat loss along the input leads, which is a function of the heater temperature. This loss changes the transfer function of the TVC as a function of the amplitude of the test voltage. The TVC output emf, e, is normally described in terms of a constant, k, associated with the TVC, the heater current, I, and the power exponent, n, by the following relationship:

$$e = kI^n, \tag{1}$$

The power exponent is determined by applying a voltage, V_1, and recording the output , e , reducing the input by a small amount (<1%) to, V_2, and recording the new output, e_2 :

$$n=V_1(e_1-e_2)/e_1(V_1-V_2). \tag{2}$$

At low current, where the temperature gradients are small, n approaches the theoretical value of 2. However, as the current increases, n may drop as low as 1.5 for some TVCs. As long as the TVC is calibrated (with a known voltage) at approximately the same output emf as that produced by the unknown voltage, the influence of the variation of n with amplitude is minimized, and the TVC remains an accurate mean-squared voltage sensor. However, as the period of the test voltage approaches the TVC time constant, e begins to track the voltage and the output develops ripple at twice the frequency of the input voltage. At very low frequencies,

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the output waveform looks like a rectified, squared version of the input waveform. For a sinusoidal voltage, n may be 2 near the zero crossing and 1.5 at the peak of the waveform. The average value of this signal will be lower than that produced by an equivalent rms voltage at a higher frequency. For the example shown in Fig. 1, the effective n is 1.77 at higher frequencies where the tracking errors are negligible.

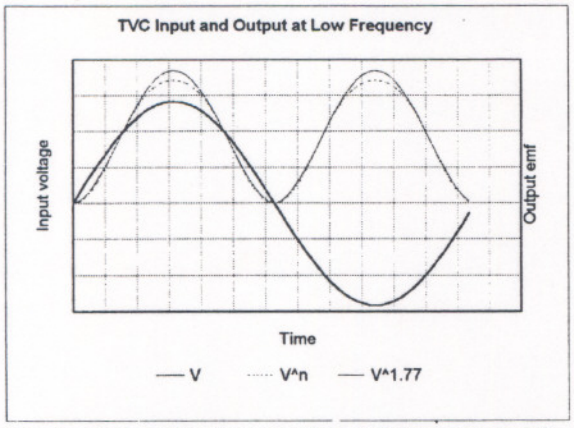

Fig. 1. Plots of the test signal V and the output emfs for n=1.77 and for n=f(V) ranging from 1.5 to 2.

2. Circuit model

To explore the nature of this tracking phenomenon, several models are being developed to relate the ac-dc difference of the TVC to its time constant and power exponent, and the amplitude, frequency, and waveform of the test voltage. These parameters are easily measured to the uncertainty required to predict the large ac-dc differences that occur at very low frequencies. A calculable DSS was used to measure the ac-dc differences that are shown in Fig. 2.

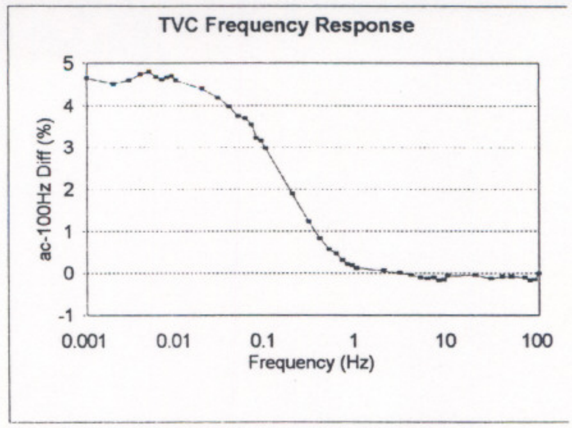

Fig. 2. Frequency response plot of the ac-dc difference of an 8 V TVC measured using the DSS as a flatness standard.

The DSS was also used as an independent method to measure the ac-dc difference of TVCs at uncertainties approaching 1 part in 10^6 at 40 Hz. These measurements will be described in the final paper.

References:

1. N.M. Oldham, P.S. Hetrick, and X. Zeng, "A Calculable, Transportable Audio-Frequency AC Reference Standard," IEEE Trans. Instrum. Meas., vol. IM-38, pp 368-371, 1989.

2. N.M. Oldham, P.S. Hetrick, and M.E. Parker, "Programmable Digitally Synthesized Source for Low-Frequency Calibrations," in Conf. Record CPEM'94, pp 419-420, 1994.

3. F.L. Hermach, "An Investigation of the Uncertainties of the NBS Thermal Voltage and Current Converters," NBSIR 84-2903, August 1984.