Student Independent Research Project : Evaluation of Thermal Voltage Converters Low-Frequency Errors

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Abstract: This paper describes a student independent research project. The project task was to evaluate the low frequency errors of Thermal Voltage Converters (TVCs). A method to evaluate the low frequency errors of TVCs has been developed ([1], [2]). This method is based on measurements of the dc transfer function and time constant of the tested TVC. The error analysis is performed in the frequency domain. The first phase of the student project was to confirm the developed method by generating MATLAB simulation based on the publications [l] and [2]. The project's second phase was to analyze the TVC errors in the time domain and compare the results.

INTRODUCTION

At the United States Naval Academy students have the opportunity to engage in research projects through the course called independent research study. It is offered to the fourth year students and it is related to the ongoing research efforts of the faculty members. It is wonderful opportunity for the interested students to obtain some research experience and it provides students prospective to the faculty member. Very often the high level research is way beyond student's comprehension. Having motivated student engaged in a project results in the focus on fundamentals. Through these discussions most of the time both the student and the teacher benefit.

TVC FUNDAMENTALS

TVC consists of a resistor, R, and a thermoelement (TE) connected in series. The resistor limits the current, I, through the TE. A TE consists of a low resistance heater to which a temperature sensor is attached. The sensor is generally a thermocouple that produces a small output electromotive force, $E_{emf,}$ proportional to the heater temperature. The heater temperature is proportional to the input power $P = I^2R$. If the amplitude of the applied AC voltage is constant and its period is small compared to the time constant of the TE, the heater temperature and the output E_{emf}, are constant. TVCs are used in this operating mode as ac-dc converters.

If the period of the applied AC voltage is comparable or even longer than the TE's time constant the heater temperature tracks the square of the instantaneous input voltage. At very low frequencies, the output E_{emf} waveform looks like a squared version of the input voltage. However, the TE heater loses heat through radiation and along its input leads. Since the loss is greater at higher temperature the peaks of the output E_{emf} will be somewhat reduced. This is a source of the significant tracking errors measured at low frequencies. In Fig. 1 measured E_{emf} is compared to the squared input voltage. The difference between their mean values is reported as TVC low frequency error. These errors are addressed in the paper.

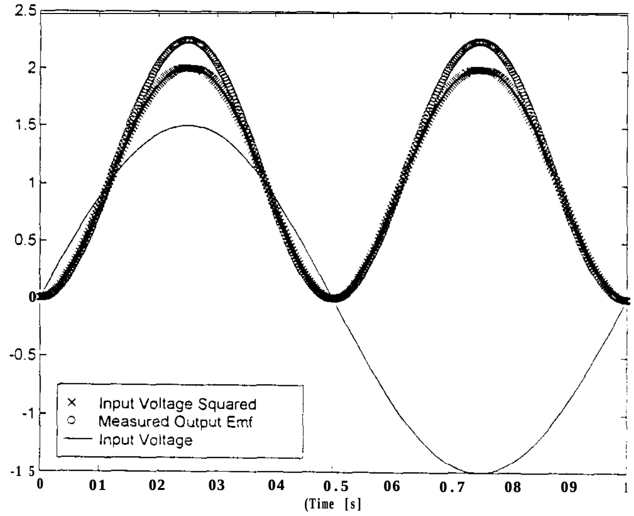

Figure 1. Comparison between measured output E_{emf} -o-, and input voltage squared, -x-.

MODEL

The simplest way to model the TVC behavior is to consider it to be the first order low pass filter. The frequency response of this filter is then used to scale the dc transfer function. The model performs the following functions:

1. Squares a simulated sinusoidal input voltage and filters it using a low pass filter with a cut off frequency f_c=1/(2n7:), where t is the TVC time constant.

2. Calculates the peak to peak variation, varpp(f), at the filter's output for a particular frequency with input voltage V applied.

3. Calculates the average output emf_{lf} at a very low frequency (where the tracking errors are maximum) with input voltage V applied.

4. Calculates the output emf_{ref} at a reference frequency (where tracking errors are negligible) with input voltage V applied.

At frequency f, the estimated ac-dc difference lambda(f) is calculated using:

$$\delta(f)= varpp(f)(emf_{ref} - emf_{lf})/emf_{ref}/n, \qquad (1)$$

where n is the power exponent that describes the transfer function of the TVC [I].

Programing this procedure was the first task the student performed. Measured TVC's transfer function and its time constant were given and the obtained results were compared to independently measured ac-dc differences. Since the performance of this approach has been already demonstrated [l, 2], this task was not very difficult and it was executed smoothly (see Fig. 2).

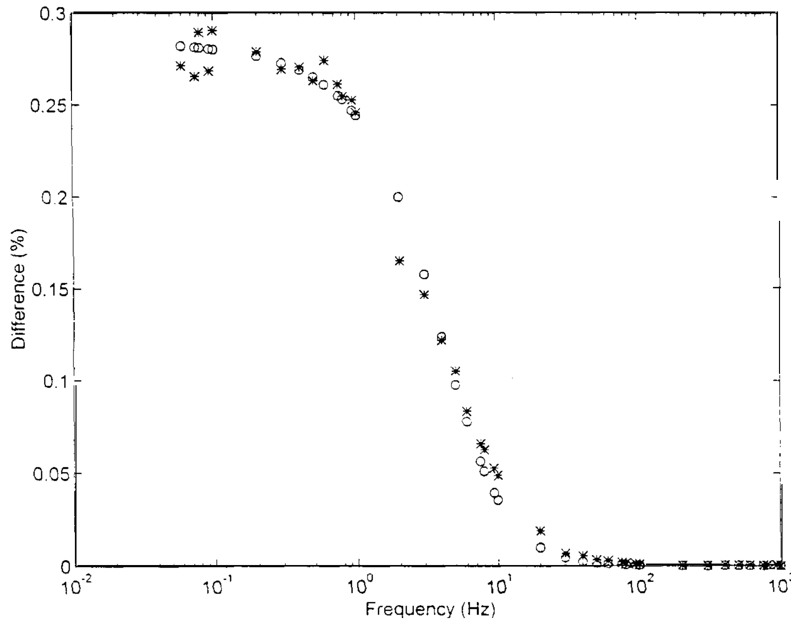

Figure 2. Comparison between simulated, -o-, and measured, -*-, ACDC differences.

TIME DOMAIN ANALYSIS

Ideally the TVC transfer function should be the parabola (input voltage squared). However, practically the power coefficient needs to be calculated for each value of the input voltage. For the given transfer functions the student calculated power coefficient (see Fig 3.). The range of coefficients, with the appropriate resolution, were given and the program picked the best fit for each measured value of the input voltage. It is not easy to measure the TVC transfer function since there is significant temperature drift. Practically, it is possible to measure the TVC transfer function for about hundred input voltage values in the TVC's optimal range of operation. Since we were interested in better input voltage resolution it was necessary to fit a polynomial curve using the calculated power coefficient. This has proven not to be the trivial task. Since the power coefficient curve is non-linear it was necessary to parse the curve into segments and fit different segments with appropriate polynomial order. It was an iterative process to arrive to the best fit (see Fig 4).

The next step was to reconstruct the TVC output emf. One idea was to use the low pas filter output voltage and apply appropriate power coefficient so that output emf could be generated. In order to compare the results of this simulation to the actual measurements the average value of the output emf has to be calculated. This part of the project was the most difficult. The simulation was developed in MATLAB and special care has to be exercised when dealing with data vectors. Even after all of the bugs were cleaned the results were not satisfactory since the ac-dc errors calculated with this method were not comparable to the actual measurements.

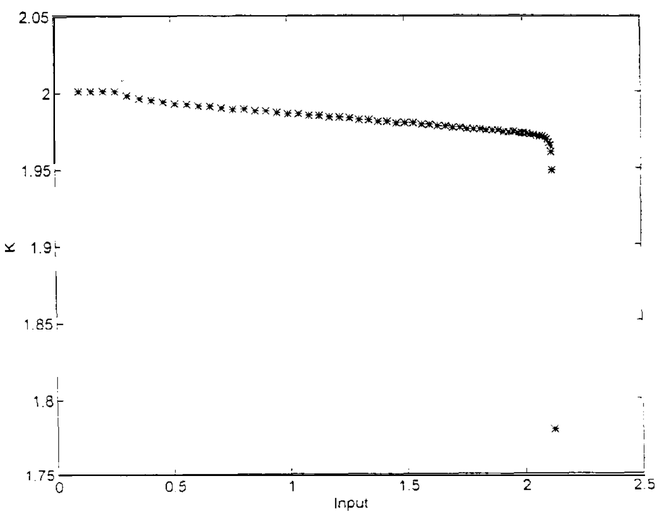

Figure 3. K values vs. input voltage.

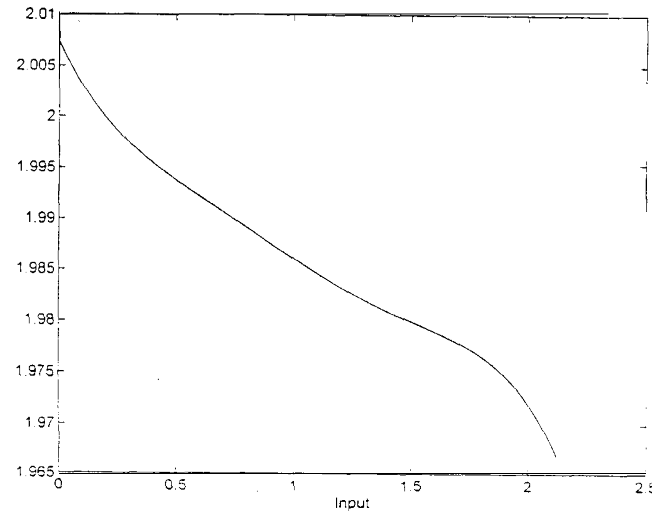

Figure 4. Polynomial fit for K values.

STUDENT'S PROSPECTIVE

There was one student working on this project for one semester. In the first phase of the project the student read number of papers and we had long discussions about modeling the properties of thermal voltage converters. This project has elements of systems identification, transfer function measurements, frequency domain analysis, filtering, as well as physics on thermal and voltage effects. The student was very excited to participate in integration of the number of concepts covered in classroom into working simulation of a real non-linear system.

Student comments:

A great deal of learning process involved the actual computer programing and working out all of the intricacies of the algorithms....Seeing classroom topics applied gave me a sense that there was a "light at the end of the tunnel" and gave me sense of satisfaction. . . . In retrospect, I did learn about the complexity of the trials and errors of the research process. I gained a whole new respect for research in general. When I read the paper now I feel I can appreciate the extensive time and effort that goes into developing it and the motivation required by the professional who write them. Given the opportunity I would like to do this again one day.

CONCLUSIONS

Student independent research project to evaluate the TVC low frequency errors was presented. The project had two phases. The first phase was to research the subject of TVC and repeat already demonstrated research [1, 21. The second phase was to attempt to calculate TVC's ac-dc difference by estimating transfer function power coefficients for each value of input voltage. The second task has never been attempted before and presented the serious effort on the student's part. It was real challenge for the student to be engaged in the state-of-the-art research and it was real motivation for the teacher to lead the true open ended project with the undergraduate student.

References:

[1] N. M. Oldham, M. E. Parker and S. Avramov-Zamurovic, “Exploring the Low-Frequency Performance of Thermal Converters Using Circuit Models and a Digitally Synthesized Source”, IEEE Transactions on Instrumentation and Measurement, Vol. 46, No. 2, April 1997.

[2] S. Avramov-Zamurovic, N. M. Oldham, M. E. Parker and B. Waltrip, “Low frequency Characteristics of Thin-Film Multijunction Thermal Voltage Converters”, accepted for publication in IEEE Transactions on Instrumentation and Measurement.

SVETLANA AVRAMOV-ZAMUROVIC was born in Yugoslavia in 1963. She received the B.S. and M.S. degrees in electrical engineering from University of Novi Sad in 1986 and 1990, respectively. From 1990 to 1994 she was involved in developing the bridge for voltage ratio calibration for the NASA space experiment, Zeno. She received the Ph.D.in electrical engineering from the University of Maryland in 1994. She has been a Guest Researcher at National Institute of Standards and Technology (NIST) from 1990 to 1994. At present she is an assistant professor at United States Naval Academy in Annapolis. In 1995 she has been involved with developing the capacitance ratio bridges to support the Single Electron Tunneling Experiment at NIST. In 1996 she developed several models of the errors of thermal voltage converters. At present she is investigating frequency characteristics of capacitors. Her research interest include precision measurements of electrical units, particularly development of bridges to measure impedance and voltage ratios.

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