

EKIT - TOOL FOR LEARNING SIGNALS, CIRCUITS AND ELECTRONIC SYSTEMS

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Keywords: Microcontroller based interfaces, Analog to digital conversion, e-Learning.

Abstract: The increase of student mobility in Europe and in other countries, and the recent attempt to harmonise European curricula at the graduation and post-graduation levels lead towards an increasing co-operation among universities to develop educational modules with a common background [5]. With Bolonha coming into effect in most universities the self-learning processes lead to the abolition of many experimental classes in the electronic graduations courses. This paper describes a project to help and promote the self-learning skills on signals, circuits and electronic systems. Experiments of measuring resistors, capacitors and DC motor parameters, show that an inexpensive USB/microcontroller device constitutes an effective minimal equipment setup.

1 INTRODUCTION

The self-learning processes imposed by the Bolonha process [2] left aside an important component of the basis of electronics engineering, namely the interaction in laboratory with the most basic physical devices. Since the signal acquisition and analysis usually requires expensive hardware such as oscilloscopes, signals generators, data acquisition devices. It seems that in fact the self-learning will be contradicting the experimental learning.

While the conventional laboratory teaching of circuits tends to decrease its prevalence, in fact the self-learning of electronics is actually growing, mostly associated to hobbies as remotely commanding model cars or planes, or by participating in robotics competitions [1]. Some of these learning dynamics can for sure be helpful for the transition process of the teaching and learning for circuit analysis, associated to the Bolonha process.

The main purpose of this paper is therefore to discuss a framework for teaching and learning circuit theory and analysis, termed the EKit project, and to show that despite the decreasing of the time of presence learning in the Bolonha paradigm, a simple hardware device still allows realizing a comprehensive va-

riety of the experiments that were standard in pre-Bolonha circuit analysis courses. The device is based on a reconfigurable microcontroller (PIC), combined with a USB interface to allow importing data directly to an ordinary desktop or laptop.

The structure of the paper is the following. Section 2 presents a general teaching and learning framework on which the USB/microcontroller device plays a major role. Section 3 details examples of experiments on electronics that can be done with the device. Section 4 draws some conclusions.

2 LEARNING AND TEACHING FRAMEWORK

The EKit project aims to provide students enrolled in Electric, Electronics and Computer (EEC) engineering courses, the necessary tools for autonomously conducting experiments similar to the ones carried out in first courses of circuit analysis. These tools are expected to be lent by the universities or in cases of personal interest, e.g. hobby applications, acquired by the students.

Commonly, first year EEC students have too lit-

the acquaintance with electronic devices. The EKit project has therefore to be user friendly in its various facets. Three very important of those facets are (i) having the required hardware capabilities, (ii) being easy to use, and (iii) being affordable. These three facets seem at first hard to fulfill simultaneously. For example first courses on circuit analysis involve using power supplies, wave signal generators and oscilloscopes, which is equipment usually not easy to use by inexperienced users and is definitely expensive.

However, there are two very important recent trends that change completely the previous scenario. The first one is that almost all students have their own personal computer (PC). The second was the introduction in the last decade of very inexpensive microcontrollers, containing very good analog-to-digital and digital-to-analog converters. Combining these two through a USB connection, one can obtain an almost complete solution: the microcontroller can generate signals to simple circuits (e.g. a voltage divider), acquire the signals of interest and send them to the PC. Then, the PC makes the role of the oscilloscope i.e. displays the resulting signals. Considering that the PC is already owned by the student, all that has to be bought is the microcontroller with the USB interface, which is certainly under the price of a text-book.

This is however an incomplete solution, not because of lacking capabilities or the price, but because it is missing the easy of use aspect, for students and teachers. Analyzing in more detail the teaching point of view, there are two additional important aspects to consider: the logistics within the university and the differentiated interfacing with the students. Both aspects should not consume additional resources of the university. Simple logistics imply that the hardware must be easy to acquire, maybe from various brands to be available from multiple vendors, easy to replace with novel versions, and simultaneously always guaranteeing that the work done at the university for the hardware is never lost. Interfacing to the students implies being able to assign specific works to the individual students and providing help. All these aspects call for flexibility on the devices, or in other words, properly designed software solutions.

Flexible software solutions comprise: (i) a webpage with drivers, software and installation manuals, (ii) a public forum for general support and discussion, and (iii) e-learning tools for distributing and grading assignments [6]. Designing a stable driver interface to the USB/microcontroller solves most of the issues related with supporting multiple brands and upgrading the hardware without losing the developed applications. The discussion forum solves most of the support to the students without too many teaching re-

sources. The e-learning tools guarantee that the student is actually self-learning, as they make possible to give differentiated assignments though individual logins and to automatically grade them. In this paper we explore precisely the differentiation aspect, by listing a variety of experiments that can be done with a USB/microcontroller device.

Considering conventional circuit analysis courses [4], the typical experiments range from resistive circuits analysis, as voltage division and load effect, till the analysis of dynamic systems as Resistor-Capacitor (RC) circuits or DC motors, both involving transient responses, time constants, DC gains, etc. In the following section on experiments we want therefore to prove that a simple USB/microcontroller device can effectively touch the concepts of most of the conventional experiments.

3 EXPERIMENTS

In these section we propose three experiments: (i) measuring resistors, using a simple voltage divider, (ii) measuring capacities based on the step response function, and (iii) measuring the DC gain and time constant of a DC motor, using techniques similar to the measurement of the capacities.

In our experiments we use mainly the USB/microcontroller device *DLP-2232PB-G* manufactured by DLP [3]. It comprises one USB-FIFO interface and one PIC Microchip 16F877A microcontroller. It is a USB 1.1/2.0 compatible and sends/receives data over USB to a host computer at up to 2 megabits per second. It has 16 digital I/O lines (5 can be configured as A/D inputs). The Microchip 16F877A has a processor with 8K FLASH ROM, 368 bytes RAM, and a multi-channel, 10-bit A/D converter.

3.1 Measuring resistors

Considering a voltage divider of a supply voltage, V_s through a calibrated resistor, R_i and a resistor load to measure, R , one has an expression for the voltage at the load, $V_r = V_s R / (R + R_i)$. Hence, if one knows V_s , R_i and measures V_r , then one can estimate R simply as:

$$R = R_i V_r / (V_s - V_r)$$

Using the USB/microcontroller device, one can easily obtain the necessary measurements. Figure 1 shows the voltage divider circuit connected to such device.

An experiment was conducted for measuring 1K, 10K and 100K resistors, using one calibrated 1K re-

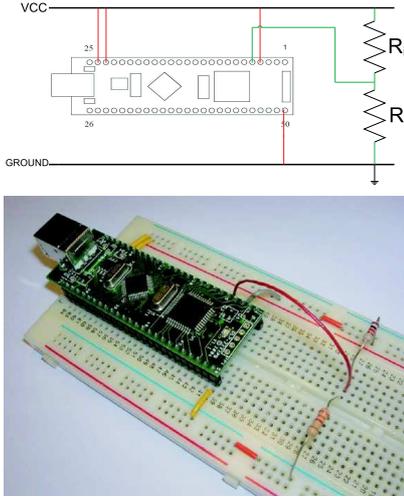


Figure 1: Resistor measuring circuit diagram (top) and image of the real setup (bottom).

sistor. The experiment was repeated 100 times for each resistor and has shown standard deviations of 0.37%, 1.09% and 7.95%, respectively. In other words, results show that the measurement noise of the device is small enough to allow using one calibrated 1K resistor to measure other resistors up-to an order of magnitude larger, within about 1% accuracy.

3.2 Measuring capacitors

A serial RC circuit is a typical way of measuring a capacity. For example one can actuate the RC circuit with a step voltage source, v_s and measure the voltage on the capacitor, $v_c(t)$. The voltage $v_c(t)$ allows calculating the time constant, τ of the RC circuit, and in case of knowing precisely the R , one obtains directly the capacity, C .

Again using the USB/microcontroller device, one can easily obtain these measurements. Figure 2 shows the device connected to the RC circuit, actuating through an output port, i.e. generating v_s and reading $v_c(t)$.

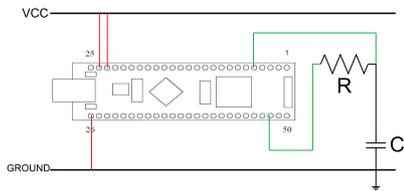


Figure 2: RC series setup to measure the capacity C .

There are several ways of measuring the capacity, C from the time response, $v_c(t)$ of a RC circuit

charged by a constant source. We will detail here three ways of estimating C , starting from: (i) the local increments of the capacitor's voltage and the integral of the current, (ii) as the previous case, but taking longer time periods, and (iii) directly the time response.

In order to apply the first two methods, one needs to estimate the capacitor's current, $i_c(t)$, which comes directly from the knowledge of v_s and R as:

$$i_c(t) = \frac{v_s - v_c(t)}{R} \quad (1)$$

The current flowing onto the capacitor is by definition the rate at which charge is being stored, $i_c(t) = C \cdot dv_c(t)/dt$. So the charge on the capacitor equals the integral of the current with respect to time, leading to $C = \int_{t_0}^{t_1} i_c(t) dt / (v_c(t_1) - v_c(t_0))$ and thus we arrive to a local formula by converting the continuous to discrete time:

$$C(k) \cong \frac{T_s}{2} \frac{i_c((k+1)T_s) + i_c(kT_s)}{v_c((k+1)T_s) - v_c(kT_s)} \quad (2)$$

where T_s denotes the sampling time and k the sample number.

In method (ii) we consider a more dilated time interval, and thus we need to account for all the local increments in the current:

$$C(k) \cong \frac{T_s}{2} \frac{\sum_{n=0}^{k-1} i_c((k+1)T_s) + i_c(kT_s)}{v_c(kT_s) - v_c(0)}. \quad (3)$$

Method (iii) uses the knowledge of the time response function, i.e. the capacitor's charging function $v_c(t) = v_s(1 - e^{-t/\tau})$ which can be solved explicitly for τ , and then for C since $\tau = R \cdot C$:

$$C(t) = \frac{-t}{R \cdot \log(1 - v_c(t)/v_s)} \quad (4)$$

where $t = kT_s$.

Figure 3 shows the time response of the RC circuit to the input voltage $v_s = 5.12[V]$, and the estimates of a capacitor with nominal value $C = 1\mu F$, using each of the three methods. It is interesting to note that despite having noisy local estimates of the current flowing on the capacitor, which has a direct impact on the estimates of C using method (i), one can obtain good results using method (ii) provided that one takes enough integration time. The result of method (ii) is smooth along time, due to its integrating nature, and is interesting even when compared to method (iii), where C cannot be estimated as soon as $v_c(t)$ gets too close to v_s . This smoothness property of (ii) is convenient for example if one does not want to implement a detector of $v_c(t) \cong v_s$.

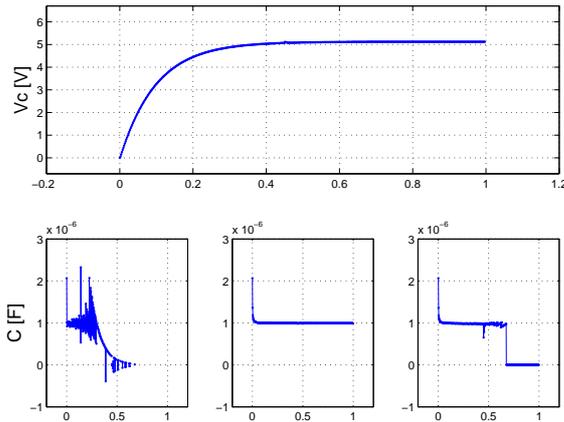


Figure 3: Time response of the RC circuit and estimates of the capacity using methods (i), (ii) and (iii) (see text).

3.3 DC motor parameters

The experiment on a brush DC motor consists on measuring its parameters from its response to a step input. In this section we will be interested in finding the parameters of a didactic DC motor setup, built by Quanser, for control courses. Figure 4 shows the power driver and the motor.



Figure 4: Power driver (left), the motor and sensors (right).

The methods for parameters estimation will follow closely the ones used for the RC circuit, since they have in essence the same model. A DC motor with the input voltage, v_s and the output angular velocity, ω can be approximately described by a first order transfer function $G(s) = k_0/(1 + \tau s)$, where τ is the time constant and k_0 is the DC gain (note that in the RC circuit $k_0 = 1$). The response of the system to the input step voltage is therefore given by:

$$\omega(t) = v_s k_0 \left(1 - e^{-t/\tau}\right) \quad (5)$$

where $\omega(t)$ is the motor speed measured as a voltage by a tachometer. This response, Eq.5 can be used as a model to estimate the motor parameters, k_0 and τ .

After acquiring the motor speed (Fig. 5) the DC gain and time constant can be estimated by two methods, inverting the step response and using a curve fitting algorithm.

Inverting the step response - Firstly we need to estimate the DC gain. Given that the step response is a monotonic function, we can estimate the DC gain from the maximum value of the step response. In order to deal with noise, in practice we estimate the DC gain from the median of all the values in a five percent range of the tachometer maximum voltage:

$$k_0 = \text{median}\{\omega(t) : \omega(t) \geq 0.95 \max(\omega(t))\} \quad (6)$$

The time constant is then calculated from Eq.5:

$$\tau(t) = \frac{-t}{\log(1 - \omega(t)/(v_s k_0))} \quad (7)$$

In order to test the above procedure we acquired step responses of the DC motor, using our USB/microcontroller device to generate the reference signals (to the power driver of the motor) and read the velocity signals generated by the tachometer. To demonstrate the potential of this microcontroller as a data acquisition device this experiment was made also with a National Instruments NI PCI-6221 signal acquisition board. Using both devices the data acquisition was conducted 200 times for the same input step voltage with a sampling frequency of about 500Hz. See Fig.5(a,b).

The time constant was computed for the time samples along the length of each experiment. Figure 5(c,d) shows that the measurement noise led to good results only in the central time-samples. Notice that the uncertainty grows as $t \rightarrow \infty$, due to the DC motor reaching the steady state. In the case of the PIC, the uncertainty is also large in the beginning which is due to some clock inaccuracy on the PC motivated by the operating system.

Hence, in order to estimate a single τ value for each experiment we selected $\tau := \tau(t)$, with t the time sample where the standard deviation of the $\tau(t)$ is a minimum considering the 200 experiments. Figure 5(e,f) shows the estimates (k_0, τ) for the 200 step responses. The uncertainty of the estimates is due to some mechanical uncertainty (the load of DC motor implies more friction in some angles) and to the measurement noise. As expected the PIC yields some more uncertainty due to its lesser precision of the analog to digital converters (10 bits, instead of the 12 bits in the NI acquisition board). Nevertheless, it should be pointed out that the difference between the two acquisition devices is less than 2% in both parameters, k_0 and τ .

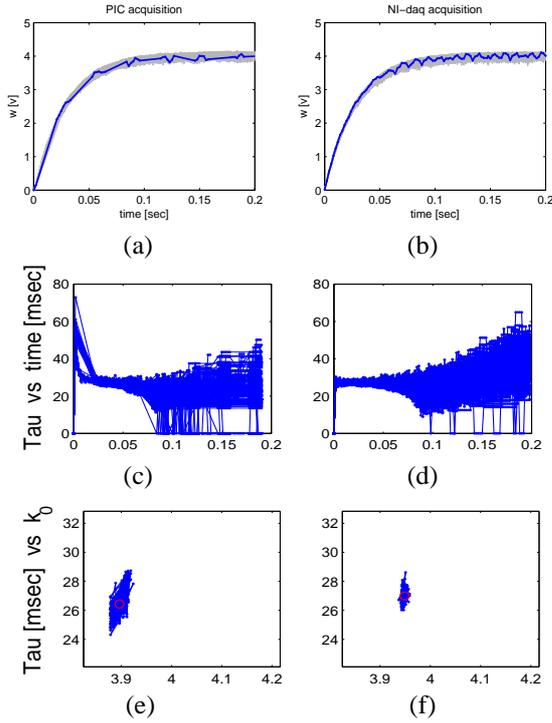


Figure 5: 200 step responses of the DC motor (a,b). PIC (left-column) and NI board (right-column). Time constant, τ [msec] estimated using Eq.7 (c,d). Time constant vs DC gain K_0 (e,f). The red circle denotes the median τ and k_0 in the 200 experiments.

Optimal curve fitting - The goal of this optimization is to find the time constant and the DC gain simultaneously so that the theoretical model (Eq.5) fits as well as possible the measurements. The cost function used in our optimization algorithm is simply a squared distance:

$$(k_0, \tau)^* = \arg_{k_0, \tau} \min \sum_{i=1}^N \left(\omega(t_i) - v_s k_0 (1 - e^{-t_i/\tau}) \right)^2 \quad (8)$$

The non-linear optimization is done in our case with the Matlab function `fminsearch` that finds the minimum of a scalar function of several variables, starting at an initial estimate.

Figure 6 and table 1 show estimates of τ and k_0 using both acquisition devices. The estimates are noisier than the ones of the previous section due to the non-existence of a data selection mechanism for removing samples not so precisely timed (timing done by the PC) or noisier due to the analog to digital conversion process (remember that τ in the previous section is estimated from the central, more precise measurements). The offset of about 1ms between the τ estimates obtained using both devices is justified mainly

by the timing imprecision at the PC. Note that the USB has itself a timing schedule that imposes some significant timing discretization errors.

Overall, table 1 shows that the NI PCI-6221 allows to obtain slightly smaller variances in the estimates. However one important observation is that the measurement of the DC motor parameters using the PIC is reliable enough for many applications and a much cheaper solution.

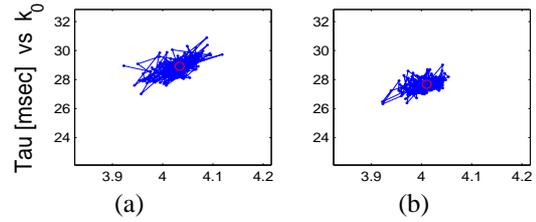


Figure 6: Time constant τ vs DC gain K_0 estimated using the optimization procedure Eq.8 based on the PIC (a) or on the NI board (b) data. The red circle denotes the median τ and k_0 in the 200 experiments.

| device | PIC | NI PCI-6221 |
|--------------------|--------|-------------|
| k_0 mean | 4.033 | 4.010 |
| k_0 std | 0.0311 | 0.0241 |
| τ mean [msec] | 28.87 | 27.66 |
| τ std | 0.6049 | 0.4301 |

Table 1: k_0 and τ comparison estimated using both devices.

4 CONCLUSIONS

With the self-learning processes imposed by Bolonha the development of cheap and accessible tools for EEC students autonomously learn and experiment circuit analysis is a priority. The Ekit was developed with the DLP-2232PB-G USB Adapter but with generic SW programming it can be used with several USB data acquisition devices. The potential of these microcontrollers along with their low cost make them a powerful and essential tool for EEC students. The experiments conducted in this paper provide first year students an experimental glance at electronic circuits.

Future experiments like filter identification, Bode diagrams, systems control (digital displays or servomechanisms), sinusoidal signal generators can be accomplished with these devices allowing them to be useful for a wider range of EEC classes. The Ekit implemented with the PIC is an excellent and above of all cheap solution for signal and data acquisition. It

provides quick learning processes and incentives future applications as well as advanced signal processing and system control studies.

5 ACKNOWLEDGEMENTS

Research partly funded by the Portuguese FCT Programa Operacional Sociedade de Informação (POSI) in the frame of QCA III, the Portuguese FCT/ISR/IST plurianual funding through the POS Conhecimento Program that includes FEDER funds and the European Project EU-FP6-NEST-5010 - CONTACT.

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