Measurement Education in Study Branch “Computer Science and Engineering”

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Abstract –The study branch concerning computer science and engineering (which offers the study programs of a number of Faculties of Electrical Engineering and Informatics) is often primarily focused on software engineering. It brings a tendency to minimize an amount of basic courses relevant to electrical engineering in this study branch. It concerns also the education in measurement and instrumentation. The paper describes the approach applied at the CTU in Prague, Faculty of Electrical Engineering to solve this matter. A content of lectures and labs of the basic course “Measurement in Digital Circuits” and briefly also of the optional course “Diagnostics of Digital Devices” is presented.

I. Introduction

The content of the study branch “Computer science and engineering” is more and more different from other branches of electrical engineering (electronic, automation, telecommunication, etc.) already at the beginning of study. There is a tendency to minimize an amount of basic courses relevant to electrical engineering in the first semesters in the number of cases. It stands for the courses concerning electrical and electronic circuits (especially analogue), electromagnetic field theory and also for measurement and instrumentation. The problem has appeared also at the CTU in Prague, Faculty of Electrical Engineering, especially in conjunction with the change over to the separate bachelor and master study stage. It is also necessary to remark that a study in the branch “Computer science and engineering” at the CTU-FEE is primarily focused on software engineering. This fact accentuates a press to minimize all courses relating to the electrical engineering.

This is a reason why the approach to relevant course of measurement and instrumentation has to be completely different than in all other branches taught at the CTU-FEE. Only the simplest principles of using the instruments for electrical quantity measurement are demanded in the basic course “Measurement in Digital Circuits”, but a bit more than basic knowledge concerning measurement in digital circuits and systems is required. (Students can gain an additional knowledge of this area in the optional course “Diagnostics of Digital Devices”, which is also guaranteed by the Dept. of Measurement. However, this course is intended for all study branches.) In this case, the requirements mentioned above together with decrease of teaching hours in the obligatory basic course “Measurement in Digital Circuits” (7 two hour lectures + 14 two hour laboratories) and the low level of entry knowledge concerning electronic circuits have led to the cardinal change in an approach to education of measurement.

II. Basic course “Measurement in Digital Circuits”

A new basic course “Measurement in Digital Circuits” has been prepared for the study branch “Computer science and engineering” with respect to the limitations mentioned above. The course should be comprehensible and interesting for students without deeper knowledge of electronic circuits. It was divided into two parts. Basic instruments and methods for measurement of electrical quantities are briefly introduced in the first part together with basic principles of measuring transducers including AD and DA converters (3 lectures, 10 laboratory tasks). The second part (4 lectures, 6 laboratory tasks) is devoted to test and measurement methods used in digital technology.

The 1st lecture (after a short introduction concerning accuracy of measurement) brings the overview of the basic instruments for measurement of voltage, current and power. An emphasis is laid on their correct application, especially with regards to the methodical error incipient by input resistance or (in case of AC measurements) by non-sinusoidal waveform due to the used type of AC/DC converter. Also the frequency dependence of DMMs is mentioned. The basic principles of measuring transducers ($U \to U$, $I \to U$, $U \to I$, converters of average and RMS value, analogue multipliers) are briefly mentioned in the 2nd lecture. More time is dedicated to the explanation of function of DA and AD converters including their basic properties and applications. The measurement of frequency, time and phase shift as well as a principle of counter is explained in the 3rd lecture. Problems that can arise when measuring in digital circuits are highlighted. The basic principle of digital RLC meter and its correct application is mentioned very briefly too.

The second part of the course is devoted to standard instruments for digital device testing and methods of their use. The principle of analogue and digitizing scopes, their features, parameters, and needful accessories are introduced at first. Methods of scope measurement in digital circuits are afterwards described with emphasis to the correct application of scope and proper interpretation of results. The next lecture is dedicated to the logic analyzers, basic methods of their application for testing and evaluation of digital circuits functionality, including processor and parallel or serial bus analysis. The possible collaboration between the scope and logic analyzer is also mentioned as well as its benefits. Finally, the simplified theory of signal propagation over the transmission line is introduced including its use in time-domain reflectometry.

The laboratory exercises are focused to the correct application of common commercial measuring instruments and to the demonstration of their weaknesses in the first part. It concerns e.g.:

- An influence of a voltage drop in the current measurement using DMM, when the supply currents of loaded bus driver (about several mA for “H” and less than 1 μA for “L” input state) are measured using low cost hand-meter, laboratory DMM (Agilent 34401A) and current-voltage transducer (see Appendix A).
- False results of voltage measurement of non-sinusoidal waveforms using low-cost hand meters (without RMS converter) and their significant frequency dependence.

The principle of S/H circuit and two types of AD converters are also demonstrated and their basic properties are measured:

- The laboratory stand, which enables both the manual control of S/H circuit and the coherent sampling of AC voltage (16 samples per period), makes possible to demonstrate a function of S/H circuit and to measure its basic parameters (see Appendix B).
- The principle of successive approximation using an 8-bit ADC is shown applying digitizing scope with both analogue and digital input (Agilent 54622A); the time behavior of clock, status bit, start pulse and serial and parallel data outputs are displayed and conversion time and clock frequency is measured.
- The demonstration of dual-slope integration ADC function, which will be replaced by $\Sigma-\Delta$ ADC next year.

The second part of laboratory tasks concerns the basic measurement methods, which are used in diagnostics of digital circuits and systems:

- The influence of production technology of digital circuits on their basic static and dynamic parameters and interpretation of the measured results in dependence on the production technology are demonstrated in two opening tasks.
- The analog scope is introduced and its contribution for digital circuit measurements is highlighted, the passive voltage probe effects are demonstrated as well as the exploitation of the delayed time base and hold-off function.
- Following lab task is focused on DSO scope, especially on synchronizing complex digital signals and manual and automated measurement of their parameters (see Appendix C).
- The logic analyzer and its application is demonstrated in 2 lab tasks. The first one is focused on its basic use in the asynchronous and synchronous modes; the second one is focused on the analysis of parallel bus communication.
- The last laboratory task shows a principle of a time domain reflectometry and its application for testing the computer network cable. The digitizing scope is used to demonstrate an influence of termination on the pulse reflection used to measure a length of short circuited or disconnected cable.

All the laboratory tasks have been selected in order to cover the expected needs that students of study branch “Computer science and engineering” will meet in further studies and in practice as well. Particular laboratory tasks not only demonstrate the principles and usage of instruments but they emphasize typical user mistakes leading to inaccurate or even rubbish results, sources of these errors, and methods that avoid or minimize them.

III. Optional course “Diagnostics of Digital Devices”

The course is focused on the test, measurement and diagnostics methods in digital technology. It is intended for all study branches, therefore some basic parts overlap with the basic course “Measurement in Digital Circuits", which is intended only for the study branch "Computer science and engineering". However, the application of standard instruments for digital device testing and methods of their use are described much deeper. The course consists of 14 lectures and laboratories within a semester; each takes two hours.

Lectures cover the three basic fields – electrical behavior of digital circuits and relative phenomena, instruments used for digital circuits debugging and methods of their use, and finally the examples of different types of digital devices and systems and common methods used for their debugging and testing. The first field starts with an overview of digital circuit technologies; particular families (bipolar, CMOS, BiCMOS etc.) are mention as well as low voltage circuit families, programmable logic types and their features. The static and dynamic parameters of these circuits are emphasized, transmission line theory is presented and digital signal integrity issues are introduced. The metastable behavior of flip-flop circuits is presented together with methods of its measurement and reduction of its influence. The second field is devoted to instruments used for test and measurement of digital devices – analog and digitizing oscilloscopes, logic analyzers, specialized communication interface analyzers and methods of their correct use. Instrument principles and methods of use are explained so that students understand possible sources of measurement errors (introduced either by instrument or by user interpretation) and ways of their reduction. Boundary Scan method and signature analysis principles are also mentioned with focus on common usage of JTAG interface also for other than only the test purposes. The last lectured area focuses on typical examples of digital devices and systems (microprocessor hardware-software co-design, measurement on serial interfaces, PCI bus analysis, CAN based system analysis at physical and link layers) and presents concrete problems, instruments and methods used for debugging.

Laboratories gain students a practical experience in above described areas. Within the first field of tasks they evaluate the static and dynamic parameters of logic circuits, use the digitizing oscilloscope for signal integrity measurements focused on events that rarely occur, test the metastability of particular flip-flop technologies using the oscilloscope with high waveform acquisition rate, and discover the behavior of transmission lines (with different types of termination). The second group of tasks is focused on correct use of measuring instruments (digitizing scopes and logic analyzers) near to their performance limits and respective issues are demonstrated as well as the ways to reduce them if possible. Boundary Scan method is used to test simple board functionality with predefined errors. Digital signature analysis method is demonstrated using stand-alone as well as the on-board implemented analyzer. The last field the laboratory course covers is focused on methods of device, interface and system data acquisition and conformity evaluation; the single chip microprocessor board, PCI plug-in card, USB device and CAN system are subjects of the test.

IV. Conclusion

The special course concerning measurement and instrumentation intended for the study branch "Computer science and engineering" was prepared and first time run in the summer semester in the year 2005. The first fractional experience showed, that students accept the course without greater problems. Since the lectures are concentrated at the 1st half of semester, whilst the laboratories are distributed during the whole semester, the corresponding topics are mostly read before the students met them in laboratory tasks. This is particularly true for second group of laboratory tasks focused on measurement of digital devices. The main disadvantage is very low amount of lectures (14 teaching hours per semester), which does not enable to explain deep enough the theoretical principles and the user approach has to be applied in number of cases. The basic overview, which is offered by this course, could be sufficient only for students interested only in software, but not in hardware application. The last should complete their knowledge in the optional course "Diagnostics of Digital Devices". The lecture slides and laboratory tasks (also in English) are accessible for students in the department web pages (http://measure.feld.cvut.cz/groups/edu/english_courses.html).

APPENDIX A - Measurement of Supply Current of Bus Driver for Different Regimes

Task of measurement

1. Measure the supply current of the loaded bus driver 74HCT573N for logic levels "log. 1" and "log. 0" at its inputs using connection according Fig. A1. Perform the both measurements:
   a) using two digital multimeters (low cost and laboratory) in mode of current measurement,
   b) using an I/U converter.
2. Find the error of the method for the case a).

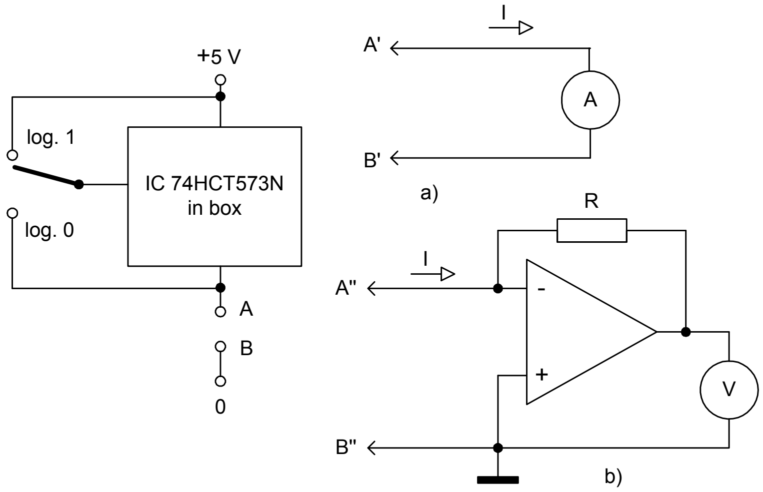


Fig. A1. Circuit for measurement of bus driver current

3. Estimate the uncertainty of measurement of current for the case b), suppose an ideal OA.

APPENDIX B - Demonstration of Signal Sampling

Task of measurement:

1. Using the sampling circuit (see the block diagram in Fig. B1) display the sampled waveform (sinusoidal signal from a function generator with frequency between 200 and 1100 Hz and the RMS value between 1 and 3 V) on the oscilloscope screen.
2. In mode “manual sampling” follow on a digital voltmeter change of the sampled value of the sample/hold (S/H) output voltage U_{out} with time (error in ”hold“ state of the sampler, so called ”droop“); find the value of this change for a selected sample level for 10 s and calculate the droop in mV/ms.
3. Using sweep magnifier (or mode ”magnified“, if dual-time base oscilloscope is used) check the waveform of the voltage U_{out} at the S/H output during the S/H settling time and find approximately the S/H acquisition time – see [1], chap.5.5.

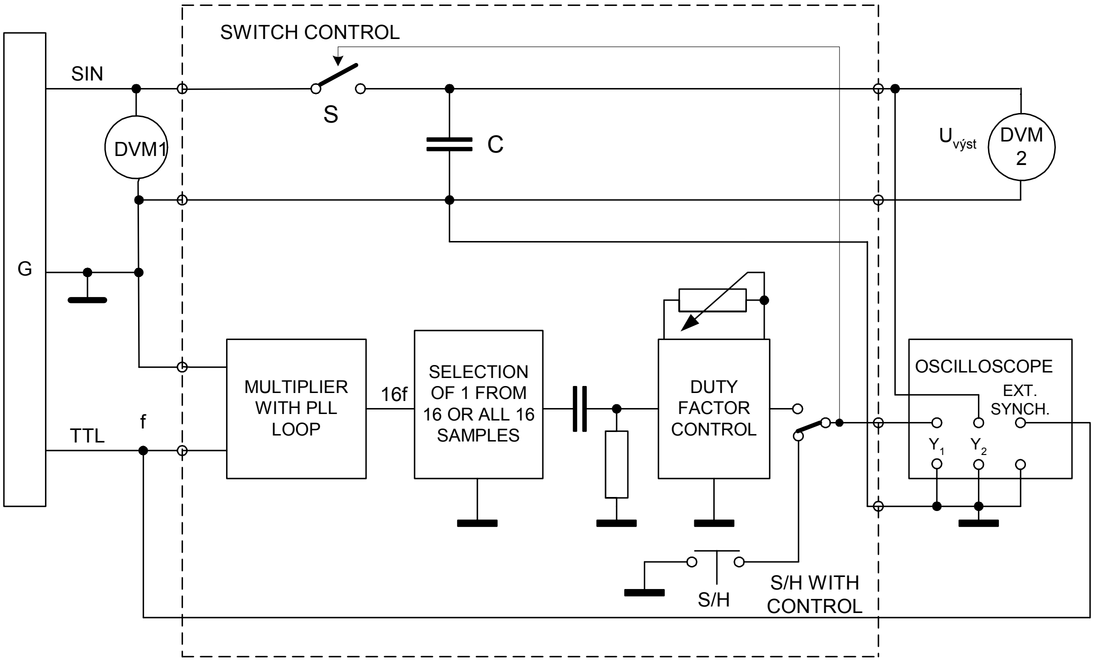


Fig. B1. Connection of sampling circuit and used instruments

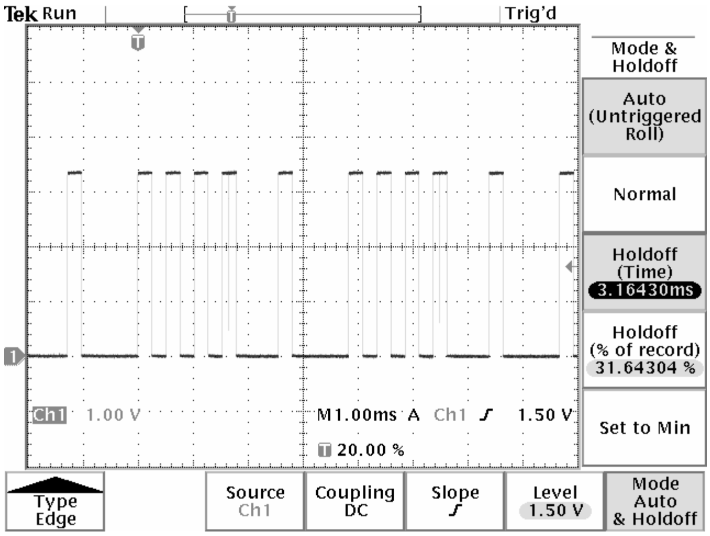
4. In the S/H mode ”1 of 16“ measure subsequently all 16 sample values across one signal period using a digital voltmeter, reconstruct graphically the sampled signal waveform, calculate the RMS value of the reconstructed signal and compare this value with the RMS value of the S/H input signal measured directly at the output of the function generator by a digital voltmeter.

APPENDIX C - Measurement with Digital Oscilloscope

Task of measurement:

1. *Compensation of the passive voltage probe.* Check the accuracy of probe compensation setting using the rectangular test signal generated by the oscilloscope or signal No. 1 of the test accessory. In case of uncompensated probe ask your instructor to fix this issue.
2. *Using the hold-off function.* Synchronize the view of signal No. 3 of the test accessory using the internal triggering and oscilloscope hold-off feature. Explain, why the hold-off time value you set at the scope is the right one.
3. *Pulse width trigger.* Synchronize signal No. 3 using minimum pulse width triggering (>). Note the glitch in the fourth pulse of log. 1 in the sequence, use the maximum pulse width triggering (<) for detail glitch view. In both cases write down the exact trigger condition and explain, why it is the right one.
4. *Pulse width measurement.* With help of oscilloscope automatic measurement function measure the width of the glitch pulse in signal No. 3.
5. *Delay measurement.* Connect the scope inputs to signals No. 5 and No. 6 of the test accessory, set the oscilloscope (you can use the *AUTOSET* button). With help of the automatic delay measurement function measure the delay between the rising and then between the falling edges of these signals.
6. *Runt pulse triggering.* Signal No. 8 contains the poor pulse of the lower log. 1 voltage level than other pulses have (probably the contention of two drivers). Set the scope to trigger at this pulse (*runt*) and using the automatic measurement function measure the voltage level of log. 1 for standard as well as for the runt pulse.
7. *Edge length trigger.* Signal No. 9 contains the poor pulse with edges longer than other pulses have (degradation or improper technology of one driver at the bus). Set the oscilloscope to trigger at this pulse and using the automatic measurement function measure the length of rising and falling edges of both the standard and poor pulse.

Remark: A special pulse generator offering 9 output signals was developed for this laboratory task. Some interesting outputs used in above described task “Measurement with Digital Oscilloscope” are shown in Figures C1, C2 and C3.



Holdoff (Time) 3.16430ms
Holdoff (% of record) 31.64304 %
Ch1 1.00 V
M1.00ms A Ch1 ∫ 1.50 V
T 20.00 %
Source Ch1
Coupling DC
Slope ∫
Level 1.50 V

Fig. C1. Test signal for hold-off function and pulse-width trigger

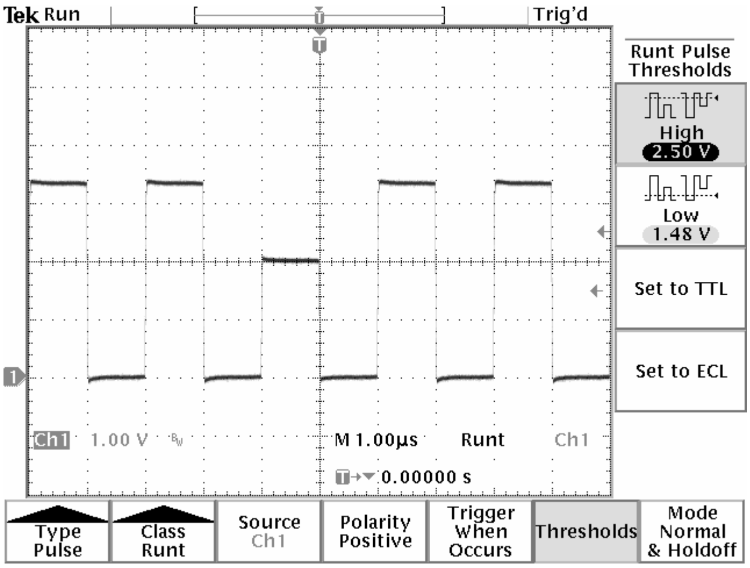


Fig. C2. Test signal for runt pulse trigger

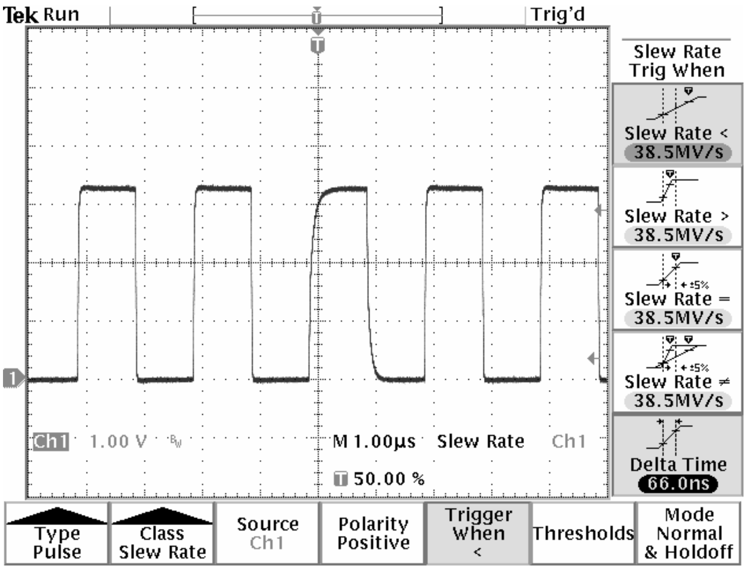


Fig. C3. Test signal for slew-rate trigger

References

[1] Haasz, V.: Changes in Education of Measurement and Instrumentation at CTU in Prague Caused by Implementation of Bologna Declaration. In *12th IMEKO TC4 International Symposium: Electrical Measurement and Instrumentation. Proceedings*. Zagreb: IMEKO TC4, 2002, vol. 1,2, pp. 535-538. ISBN 953-96093-7-2.