September 10 - 12, 2007
Pilsen, Czech Republic

# EDUCATION OF ANALOGUE ELECTRONIC CIRCUITS SUBJECT IN ECT BACHELOR FIELD OF STUDY

DOC. ING. LUBOMÍR BRANČÍK, CSC.

**Abstract**: *The subject Analoque electronic circuits plays important role within the framework of three-years bachelor field of study Electronics and communication technology at FEEC BUT in Brno. The paper discusses restructuring and innovative steps implemented in the light of requirements resulting from teaching process in attendance and combined forms of study.*

**Key words**: *Analogue electronic circuits, Lectures, Exercises, Computer exercises, Laboratory exercises, Computerized system*

## INTRODUCTION

The subject Analogue Electronic Circuits (AEC) is a compulsory subject of bachelor field of study Electronics and Communication Technology (ECT) at the Faculty of Electrical Engineering and Communication (FEEC), Brno University of Technology (BUT) in Brno. The aim of this subject is to make students familiar with basic principles of analog electronic circuits, to show an utilization of a personal computer (PC) at their analysis and to verify their properties by means of practical measurements of typical electronic circuits. The going through the course AEC is an essential professional training for successful studying another specialized subjects including those of subsequent magister field of study ECT. Education forms well structured, study materials created synoptically, their composition and linkage are thus very important factors at the arrangement of the high-quality education.

In the paper a current state and proposed changes are discussed while reflecting needs for both attendance and combined forms of study.

## 1 BASIC STRUCTURE OF THE SUBJECT

The subject Analogue Electronic Circuits is annually opened up for roughly 250 and 25 students at attendance and combined forms of study, respectively. Besides, a few foreign students in a fee-based form of study attend the subject being taught in the English language. Due to specific needs at teaching in the above stated study forms it has been necessary to prepare different forms of tuition accordingly. Firstly, the organisation and syllabi of the basic attendance form of study are discussed.

### *1.1 Subject organisation and syllabi*

To enter the AEC course a subject knowledge on the secondary school level is requested. In addition, for those students who have passed out humanities a passing the seminar Practical electronics (PE) is needed. The subject AEC is covered by 26 lessons of lectures, 13 lessons of exercises, 13 lessons of computer exercises and 26 lessons of laboratory exercises. The following items are evaluated: • performance of all laboratory measurements and passing their reports (up to 15 points), • active participation on all computer trainings (up to 15 points), • verification test within the framework of numerical exercises (up to 10 points), and • written form of the final semestral exam (up to 60 points). The students can obtain at the most 100 points, 50 points is a minimum to pass. Besides, based on a simultaneous completion of both computer and laboratory exercises the obtaining credit is needed to pass out the subject.

In light of contents the following topics are included in the subject regardless of the form of study: • Electronic circuits: basic concepts and classification, • Electronic circuit elements: two-poles, two-ports and multiports, • Modelling of the real circuit elements: semiconductor diodes, bipolar (BJT) and field effect transistors (FET), operational amplifier (OA), • Electronic circuit as a linear dynamical system: stability, feedback, • Circuits with the operational amplifiers: voltage and current amplifiers, converters, • Electrical filters: principle, passive and active filters, applications, • Basic stages with transistors: common-emitter (CE), common-collector (CC) and common-base (CB) connections, frequency properties, • Transistor circuits: current sources, current mirrors, Darlington circuit, casdade connections of basic stages, differential amplifiers, • Amplifiers: classification and function, wideband, narrowband and power amplifiers, • Power supplies: stabilizers, rectifiers and converters, • Signal converters: shaping networks, multipliers, modulators and mixers, • Signal generators: oscillators.

| *No.* | *Lectures* |
|---|---|
| 1. | Electronic circuits, their purpose, classification and parameters. |
| 2. | Circuit elements and functional blocks. |
| 3. | Modelling of real circuit elements. |
| 4. | Circuit as a linear dynamical system, stability, feedback. |
| 5. | Circuits with operational amplifiers. |
| 6. | Electrical filters. |
| 7. | Basic circuits with BJT and FET transistors. |
| 8. | Multistage circuits with transistors. |
| 9. | Amplifiers, LF, HF, wideband, narrowband, with tuned circuits, power. |
| 10. | Power-supply units, rectifiers, stabilizers, DC/DC converters. |
| 11. | Signal converters and shaping circuits, mixers, modulators and demodulators. |
| 12. | Signal generators, oscillators LC, RC, with PCU, tuned electronically. |
| 13. | Lecture finalization, discussion, questions. Information to written final semestral test. |
| *No.* | *Exercises* |
| 1. | Summary of linear circuit analysis methods, nonlinear circuit elements, graphical solution. |
| 2. | Circuit elements models, analysis of linearized circuits. |
| 3. | Circuits with operational amplifiers. |
| 4. | Linear system, stability, feedback. |
| 5. | Verification test. |
| 6. | Electrical filters, basic circuits with BJT and FET. |
| 7. | Rectifiers, shaping networks, LC and RC oscillators. |
| *No.* | *Computer exercises* |
| 1. | Introductory information, mathematical model of a circuit, solution in the MATLAB program. |
| 2. | Symbolical circuits analysis in the SNAP program. |
| 3. | Basic introduction to the PSPICE program, verification of basic circuit theorems. |
| 4. | DC and AC analysis of electrical circuits, real OA properties, BJT (PSPICE). |
| 5. | Time analysis, models of basic elements, simulation of selected analog circuits (PSPICE) |
| *No.* | *Laboratory exercises* |
| 1. | Introductory exercise, safety instructions. |
| 2. | Operational amplifier - properties and applications. |
| 3. | Transistor amplifier and limiter. |
| 4. | Half-wave and full-wave diode rectifiers. |
| 5. | Amplifiers with integrated OA. |
| 6. | Final test. Obtaining credits. |

*Tab. 1: AEC syllabi – attendance form of study*

The syllabi of all the tuition forms are presented in Tab. 1 just for the attendance form of study. In case of the combined form of study there are the same requirements as for knowledge granted to give to students, however, different tuition forms are used to achieve it.

### *1.2 Specificity in combined form of study*

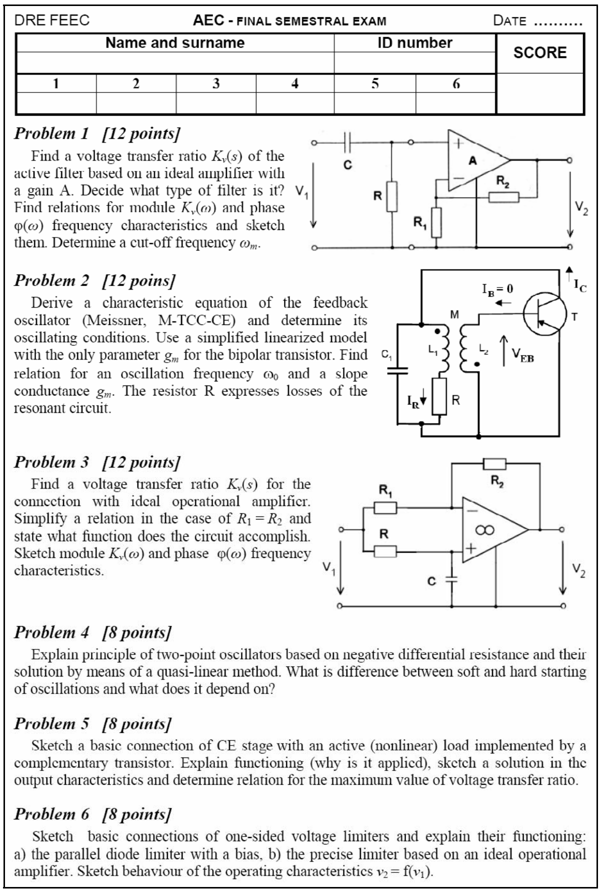
In the combined form of study the tuition is organized in the form of tutorials, computer/laboratory exercises and homeworks. There are 4 tutorials held within the range of 10 lessons per semester covering all the topics from the lectures in Tab. 1. At the end of each tutorial, a homework is submitted having to be solved till specified date. It means that 4 homeworks are evaluated leading to up to $4 \times 7 = 28$ points. The computer exercises are withing the range 2 lessons per semester collected into the only practising, therefore, only 1 topic from Tab. 1 is always selected to be solved. The same is valid for the laboratory exercises. The passing out both practising is mandatory to be able to obtain a credit, and up to $2 \times 6 = 12$ points can further be obtained. The remaining 60 points is reserved for the written final semestral exam which is held jointly with the attendance form of study to keep the same demands.

### *1.3 Specificity in education of foreign students*

A few foreign students can enter the AEC course as a optional subject in the frame of fee-based form of study. For these students it was necessary to prepare some materials in English. Specifically, the textbook Analogue electronic circuits [4] has newly been written as the electronic text being accessible at www of the faculty. Besides, the English version of the lectures is available in an electronic form in the PowerPoint format.

## 2 TYPICAL TASKS AND EXAMS EVALUATED

As was mentioned above specific tasks and exams are evaluated in each form of tuition within the framework of a particular form of study. Here some examples are only shown to demonstrate typical requirements for students. First the written final semestral exam is jointly organized for students of attendance and combined form of study. It consists of typically 3 examples to be solved (either symbolically or numerically) and 3 theoretical questions to be answered in writing. An example is shown in Fig.1, available time for the solution is 120 minutes. As for the verification test within the framework of exercises it is organized after a half of the semester period, and is composed of 2 or 3 examples to be solved during about 50 minutes. These examples are similar to those in the final semestral exam as for their difficulty. During the computer exercises it is no special exam, however, an active work is observed by a teacher and an evaluation is performed at the end of each session. As a result of the laboratory exercises the reports of all the measurements must be processed. Each report should be handed over till the next session, and preparation of a new measurement is to be shown for the inspection. In the last session a final test is organized mapping knowledge of all the laboratory tasks, and a credit is given.


DRE FEEC AEC - FINAL SEMESTRAL EXAM DATE ..........

| Name and surname | | | | ID number | | SCORE |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | |
| | | | | | | |

***Problem 1** [12 points]*
Find a voltage transfer ratio $K_v(s)$ of the active filter based on an ideal amplifier with a gain A. Decide what type of filter is it? Find relations for module $K_v(\omega)$ and phase $\varphi(\omega)$ frequency characteristics and sketch them. Determine a cut-off frequency $\omega_m$.

***Problem 2** [12 poins]*
Derive a characteristic equation of the feedback oscillator (Meissner, M-TCC-CE) and determine its oscillating conditions. Use a simplified linearized model with the only parameter $g_m$ for the bipolar transistor. Find relation for an oscillation frequency $\omega_0$ and a slope conductance $g_m$. The resistor R expresses losses of the resonant circuit.

***Problem 3** [12 points]*
Find a voltage transfer ratio $K_v(s)$ for the connection with ideal operational amplifier. Simplify a relation in the case of $R_1 = R_2$ and state what function does the circuit accomplish. Sketch module $K_v(\omega)$ and phase $\varphi(\omega)$ frequency characteristics.

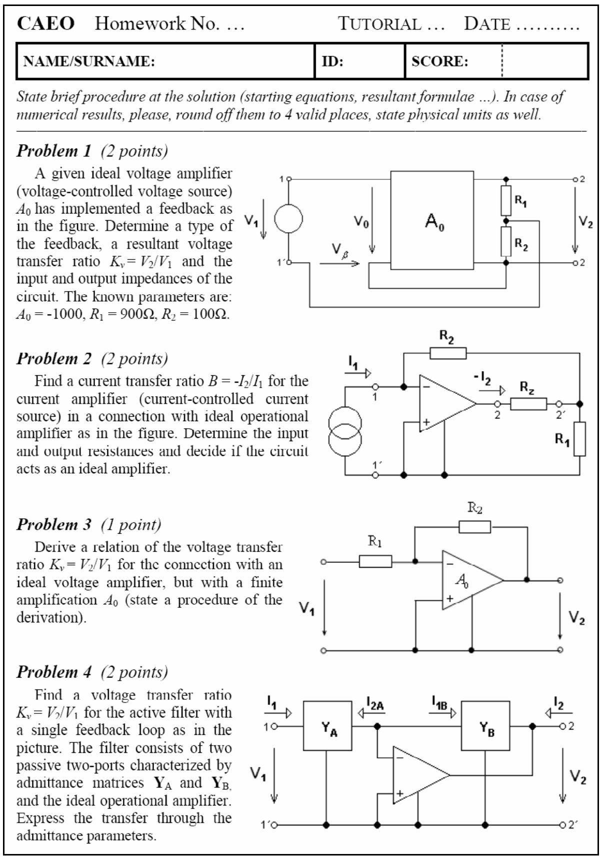
***Problem 4** [8 points]*
Explain principle of two-point oscillators based on negative differential resistance and their solution by means of a quasi-linear method. What is difference between soft and hard starting of oscillations and what does it depend on?

***Problem 5** [8 points]*
Sketch a basic connection of CE stage with an active (nonlinear) load implemented by a complementary transistor. Explain functioning (why is it applied), sketch a solution in the output characteristics and determine relation for the maximum value of voltage transfer ratio.

***Problem 6** [8 points]*
Sketch basic connections of one-sided voltage limiters and explain their functioning: a) the parallel diode limiter with a bias, b) the precise limiter based on an ideal operational amplifier. Sketch behaviour of the operating characteristics $v_2 = f(v_1)$.

*Fig. 1: Example of written final semestral exam*

In case of the combined form of study homeworks are assigned at the end of each tutorial. A typical homework consists of 4 examples being solved in writing, see Fig. 2.


CAEO Homework No. … TUTORIAL … DATE ……….

| NAME/SURNAME: | ID: | SCORE: |
|---|---|---|

*State brief procedure at the solution (starting equations, resultant formulae …). In case of numerical results, please, round off them to 4 valid places, state physical units as well.*

***Problem 1** (2 points)*
A given ideal voltage amplifier (voltage-controlled voltage source) $A_0$ has implemented a feedback as in the figure. Determine a type of the feedback, a resultant voltage transfer ratio $K_v = V_2/V_1$ and the input and output impedances of the circuit. The known parameters are: $A_0 = -1000$, $R_1 = 900\Omega$, $R_2 = 100\Omega$.

***Problem 2** (2 points)*
Find a current transfer ratio $B = -I_2/I_1$ for the current amplifier (current-controlled current source) in a connection with ideal operational amplifier as in the figure. Determine the input and output resistances and decide if the circuit acts as an ideal amplifier.

***Problem 3** (1 point)*
Derive a relation of the voltage transfer ratio $K_v = V_2/V_1$ for the connection with an ideal voltage amplifier, but with a finite amplification $A_0$ (state a procedure of the derivation).

***Problem 4** (2 points)*
Find a voltage transfer ratio $K_v = V_2/V_1$ for the active filter with a single feedback loop as in the picture. The filter consists of two passive two-ports characterized by admittance matrices $\mathbf{Y}_A$ and $\mathbf{Y}_B$ and the ideal operational amplifier. Express the transfer through the admittance parameters.

*Fig. 2: Example of homework in combined form of study*

# 3 EDUCATIONAL-TECHNICAL SUPPORT

Excluding materials supporting an education of the foreign students, each form of tuition is supported by a textbook in Czech language accessible as the electronic text at www of the faculty. Currently three textbooks are available: AEC–Lectures [1], AEC–Computer exercises [2] and AEC–Laboratory exercises [3], however, they are being innovated this time. The textbook AEC–Lectures [4], written in English, plays a role of a basic text for the foreign students and a recommended text for the students of the attendance and combined forms of study. The last text, AEC–Exercises, is being written as a new text to support possibilities of independent practising.

As for the technical facilities the computer lab of the Department of Radio Electronics (DRE) with a capacity of 28 students is utilized for the computer exercises, see Fig. 3. The PC lab has recently been built up (2006) to enable teaching bigger number of students effectively.

*Fig. 3: Computer laboratory at DRE*

The laboratory exercises are held in the lab of analog circuits of the same department with a capacity of 10 students, each of them working independently, see Fig. 4.

*Fig. 4: Laboratory of analog circuits at DRE*

The instrumentation is regurally brought up to date or completed, mostly based on grant projects of the Czech Ministry of Education. For example, this year author's grant project *Restructuring and Innovation of Compulsory Subject Analogue Electronic Circuits* solves not only the innovation of the above stated textbooks but also a design of a new demonstrational laboratory exercise.

## 4 COMPUTERIZED MEASUREMENT SYSTEM

Within the framework of an innovation of teaching methods the new computerized measurement system is planned to be included into the introductory laboratory session starting with the winter semester 2007/08. It is intended for demonstrational measurements of electronic functional blocks, namely the frequency characteristics of electrical filters (both passive and active) and amplifiers, DC operating characteristics, and others. A block diagram of such the computerized measurement system is shown in Fig. 5.

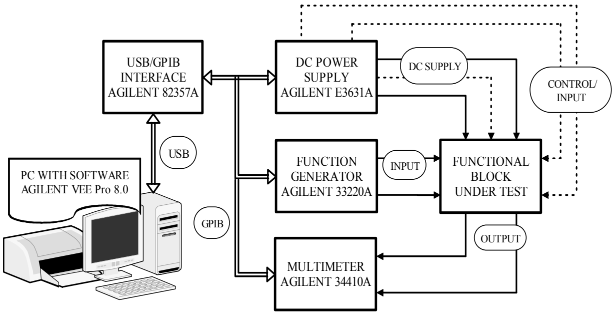



*Fig. 5: Block diagram of measurement system*

The system is controlled by a PC with Agilent VEE Pro 8.0 (VEE – Visual Engineering Environment) [5 - 7]. It is a graphical programming language designed for controlling measurements, and collecting and processing data being measured. The USB/GPIB interface Agilent 82357A is used as the only connection to the PC, three remaining instruments are interconnected via the GPIB bus. These are: the 20MHz function/arbitrary waveform generator Agilent 33220A, the 6½ digit multimeter Agilent 33220A and the triple output DC power supply Agilent E3631A (0 – 6V, 5A and 0 – ±25V, 1A). Due to the power supply's controllable DC voltage outputs, it is possible to test both DC operating characteristics and frequency characteristics of the active functional blocks with voltage-controlled parameters. The built-up system in reality is shown in Fig. 6.

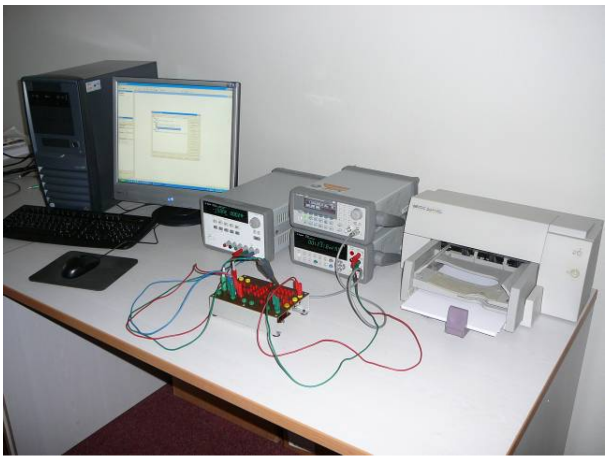


*Fig. 6: Built-up computerized measurement system*

The Agilent VEE Pro package can also play a role of a powerful computational tool, with many mathematical functions and graphical outputs. A solution of a Campbell passive filter leading to graphing its magnitude and phase characteristics is depicted in Fig. 7, as an example of the VEE Pro environment. The complex voltage transfer ratio

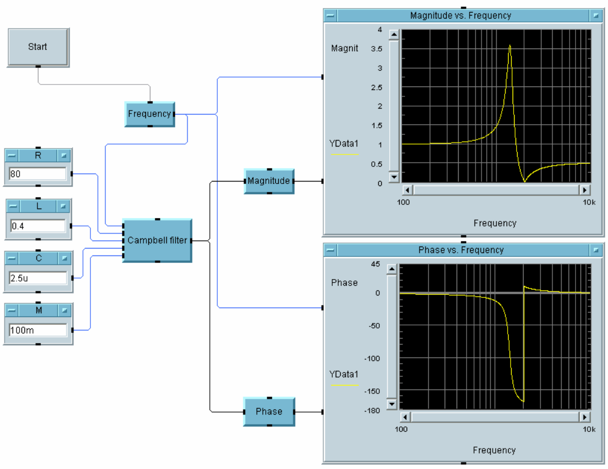



*Fig. 7: VEE Pro environment (Campbell filter)*

which depends on 4 input parameters, *R*, *L*, *C* and *M*, is defined inside the block *Campbell filter* [8]. A proper frequency array is generated in the block *Frequency* by using *ramp* function inside, blocks *Magnitude* and *Phase*, containing respective functions *mag(x)* and *phase(x)* inside, treat the output complex array to graph both characteristics using *X vs Y Plots*, renamed respectively.

The above stated example implies another very useful application of the computerized system. Namely, it will enable to do an immediate comparison of results gained on the basis of measurements of real functional blocks to results gained on the basis of theoretical models defined analytically. To measure phase characteristics, however, the measurement system will be completed by a digital oscilloscope with a specialized module in a near future.

## 5 REFERENCES

[1] Dostál, T.: Analogové elektronické obvody (Analogue electronic circuits). E-text, FEEC BUT in Brno, 2004.

[2] Dostál, T., Kolka, Z.: Analogové elektronické obvody - Počítačová cvičení (Analogue electronic circuits - Computer exercises). E-text, FEEC BUT in Brno, 2003.

[3] Jakubová, I., Kovářová, J.: Analogové elektronické obvody - Laboratorní cvičení (Analogue electronic circuit - Laboratory exercises). E-text, FEEC BUT in Brno, 2003

[4] Brančík, L., Dostál, T.: Analogue Electronic Circuits. E-text, FEEC BUT in Brno, 2006.

[5] Agilent VEE Pro 8.0 - Quick Start Guide: Agilent Technologies, Inc., Malaysia, February 2007.

[6] VEE Pro User's Guide: Agilent Technologies, Inc., U.S.A, Ninth edition, May 2005.

[7] VEE Advanced Techniques: Agilent Technologies, Inc., U.S.A, Second edition, March 2004.

[8] Schieblová, J., Brančík, L.: Teoretická elektrotechnika II. Sbírka příkladů. (Theoretical electrical engineering II. Exercises). Textbook BUT in Brno, PC-DIR Brno, 1996.

## ACKNOWLEDGMENTS

Presented work has been financially supported by the Czech Ministry of Education under the FRVŠ 418/2007 grant project and MSM 0021630503 research project MIKROSYN.

***Author***: *doc. Ing. Lubomír Brančík, CSc., Brno University of Technology, Department of Radio Electronics, Purkyňova 118, 612 00 Brno, Czech Republic, E-mail: brancik@feec.vutbr.cz*