A Course on Electronic Circuits Laboratory for a Masters' Programme in Electrical Engineering

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Abstract - Masters programmes in engineering are expected to produce graduates well suited for design, and research and development (R & D) activities. Graduates, particularly in power electronics and related areas, are required to have excellent hardware skills. This paper presents a transitional course on electronic circuits, meant to enhance the design and development skills of students in a Master's programme in electrical engineering. The course also helps the students better understand and relate the fundamentals of electronic circuits, circuit theory and control systems. The effectiveness of the course is assessed through student feedback. The feedback indicates a significant improvement in the students' understanding of basic concepts and measurement techniques, familiarity with electronic components, confidence in design of electronic circuits, and assembly and testing skills.

Index terms: Engineering education, pedagogy, electronic circuits, design and development

I. Introduction

Post-graduate (PG) programmes in engineering should produce strong candidates for design and R&D positions in the industry, or a career in research and/or teaching. Good design and development skills are essential, or at least very much desirable, for all the above career options. Requirement of design and development skills for industrial R&D positions is obvious. These skills enable research scholars and researchers to pursue high-quality experimental research. Teachers with such skills can impart the same to students through guidance of projects involving considerable hardware. PG programmes, involving power electronics, should aid students to acquire excellent design and development skills in the domain of power electronic converters.

A power electronic system can be broken up into power circuit, low-power electronic circuitry, and controller. The power circuit typically consists of power semiconductor devices (such as MOSFETs and IGBTs), capacitors, and magnetic components such as inductors and transformers. The low-power electronic circuitry includes gate drive, protection and fault annunciation, besides isolated measurement, scaling and buffering of analog signals. The controller could be analog or digital. Digital controller includes both hardware and software, and could be based on a microprocessor, microcontroller, DSP processor or programmable logic device.

Hence, to enhance the students' design and development skills pertaining to power electronic converters, one needs to focus on four aspects – power semiconductor devices, magnetic components, digital controllers and electronic circuits. Hence it is helpful to develop the following capabilities in students:

a) Design with power semiconductor devices including thermal, snubber and bus-bar design
b) Design, fabrication and testing of magnetic components
c) Digital controllers – programming, design and development
d) Design and development of electronic circuits

Ability to design with power semiconductor devices- including aspects of drive, protection, snubber and thermal management - is perhaps the most critical skill required in developing power electronic converters. While the curriculum usually deals with design of inductors and transformers at line frequency, both line-frequency and high-frequency considerations are important in design and fabrication of magnetic components used in power converters. Design, assembly and testing of simple power converters with only a few switches (e.g. dc-dc boost converter, isolated flyback converter) and of low ratings could be enough to get the students started in acquisition of skills pertaining to devices and magnetic components. Recently, some efforts have been made in this regard [1-2].

Electronic circuits and digital controllers are of interest to several specializations besides power electronics such as power systems, control and instrumentation, industrial electronics and applied electronics.

Of the four capabilities listed above, design and development of electronic circuits is perhaps the most fundamental and of broadest interest. This is necessary for design and development of digital controllers. Ability to handle electronic components at low power levels could prepare the students better to work with power semiconductor devices.

This paper deals with a course meant to enhance the design and development skills of students in analog and digital circuits. This course is an educational experiment to examine whether the design and development skills of students, with regard to electronic circuits, can be enhanced through a formal laboratory course.

The course is a 1-credit elective course in a two-year ME programme in Electrical Engineering (64 credits). The ME programme is a combination of power systems, power electronics and high voltage engineering. The scope and details of the course, course administration, student feedback and assessment of the effectiveness of this course are dealt with in the following sections.

II. Course Objectives and Content

Design and development of electronic circuits requires a sound understanding of fundamentals and certain skills. While the ingredients of such design and development skills are difficult to enlist, an attempt is made in this regard in the following discussion.

To design and develop electronic circuits, a sound knowledge of electronics and related subjects such as circuit theory and control systems is essential. A high degree of familiarity with commonly-used electronic components (discrete components and ICs) is also required. This includes knowledge of technical specifications of the components and also hands-on experience with them. Further, an ability to assemble the components into a circuit is necessary. This included bread-boarding and soldering skills, and familiarity with circuit boards.

Testing and trouble-shooting – testing individual components, identifying the trouble-spot in a circuit.

Hence, the objective of the course is to strengthen the following aspects:

a) Fundamentals of electronic circuits and related subjects such as circuit theory, control systems and mathematics
b) Familiarity with electronic components and basic electronic circuits
c) Development of assembly, testing and trouble-shooting skills
d) Confidence in design of electronic circuits

The course content as in the students' handbook is as follows:
Linear and nonlinear applications of operational amplifiers, inverting and non-inverting amplifiers, differential amplifiers, phase-shifting circuits, active filters, oscillators, comparators waveform generating circuits; logic circuits, flipflops, counters and timers; voltage controlled oscillators, phase locked loops, frequency multiplier and divider circuits; electronic circuits relevant for power electronic converters, power systems measurements and protection of power apparatus.

As can be seen, the content of this course is quite similar to that of the undergraduate course on electronic circuits. However, there are two significant differences. Firstly, certain exercises such as dead-time circuit, and fault annunciation and protection circuits are oriented towards power electronic converters. Secondly, individual exercises in this course are broader in scope than their counterparts in the undergraduate (UG) level course. Some examples in this regard are indicated below.

- Power supply currents drawn by electronic circuits
- Measurement of step response and frequency response of active filters and phase shifters
- Correlation between step response and frequency response of linear systems (filters, phase shifters etc)
- Ratings, tolerances and specifications of discrete components
- References to datasheets of op amps and other ICs
- Variation in gain or transfer characteristic of circuits due to component tolerance
- Analysis and measurement of input and output resistances/impedances of amplifiers and other circuits (see Figs. 1 and 2)

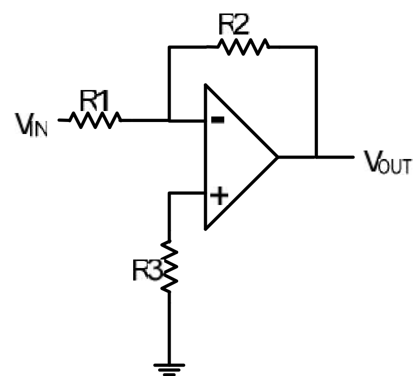

Fig. 1. Inverting amplifier

The inverting amplifier, shown in Fig. 1, has an input resistance R1. The exercise on inverting amplifier includes measurement of the input resistance, as illustrated in Fig. 2, by measuring the loading effect of the amplifier on the output of the potential divider formed by R_A and R_B. Similarly, the exercise on differential amplifier includes analysis and measurement of the common-mode as differential-mode input resistances of the amplifier.

The study of input resistance, output resistance and power supply current brings out how the circuit is viewed by the source (driving circuit), the load (driven circuit) and the power supply. Such an understanding helps designing complex circuits using simple circuits as building blocks.

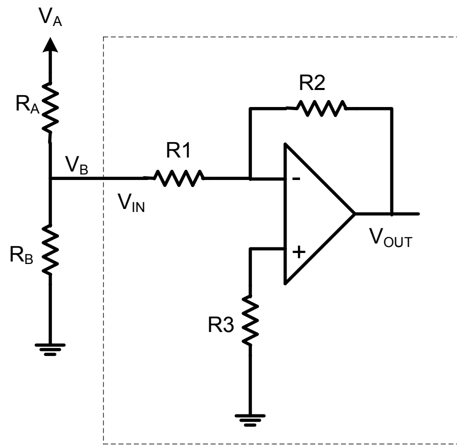

Fig. 2. Loading effect of the inverting amplifier

III. Course Material and Methodology

The course in question is a laboratory course, having a 3-hour lab session every week for 16 weeks. During the first 12 weeks, students are given a common set of laboratory exercises, designed appropriately to meet the course objectives. Every student is required to complete an individual mini-project during the last four weeks. The mini-projects are usually of a challenge level higher than the common set of experiments. The evaluation of students and grading are based on the regular experiments as well as the mini-project.

Being a laboratory course, there is no instruction through lectures. Hence the course material developed is of critical importance to the success of the course. An instruction set is prepared for every exercise. The instruction sets should aid the students to improve their familiarity with electronic components, to analyze and design electronic circuits, and to experimentally validate the analytical models and designs based on such models.

Certain steps in a few exercises guide the students to learn about the ratings, tolerances and specifications of discrete components such as resistors, capacitors and diodes. Similarly, a few steps in various exercises direct the students to datasheets of integrated circuits (ICs) to learn certain technical specifications of ICs such as operational amplifiers, comparators and logic gates.

The instructions take the students through different levels of analysis of the circuit - idealized analysis, incorporation of non-idealities, and inclusion of the effects of component tolerances. Correspondingly, the design steps include design based on idealized model, and design with compensation for non-idealities and component tolerances.

The design activity in the initial experiments mainly concerns (i) selection of component values for a given circuit and (ii) design of a part of a circuit. The later exercises involve design of complete circuits. Thus, the design activity in the course is graded in terms of challenge level - selection of component values, design of a part of a circuit, and design of a complete circuit.

Table I lists the various exercises and the learning goals of each. The instruction set for every exercise takes into account the specific learning goals for the exercise and the overall objectives of the course as discussed above. Every exercise has multiple sections, each of which has a number of steps. Steps concerning datasheets, analysis and design are required to be completed at home (before the start of the lab class). The other steps, concerning validation of analytical models and designs, are carried out in the lab. The lab work provides hands-on experience, enhancing the assembly and testing skills of the students.

Apart from these laboratory instruction sheets, the students might need to refer to standard textbooks on electronics [3-4], and datasheets and application notes from manufacturers.

IV. Course Feedback and Analysis

Effectiveness of the course is assessed through student feedback. Design of the feedback form, quantitative analysis of the feedback received, and inferences therefrom are presented in this section. Steps for further action are also discussed.

A. Feedback form

To examine the effectiveness of the course with regard to strengthening the knowledge of electronics and related subjects, students are asked to respond on their understanding of important topics. The feedback form lists 23 topics. Against each topic, students are asked to indicate where they stood at the start of the semester (in their own assessment). The options given are: did not know (D), poor (P), fair (F), good (G), and very good (VG). Students are also asked to state how much improvement he/she has made (in his/her own assessment) on each of these items. The options provided are: no improvement (No), marginal improvement (M), significant improvement (S) and very good improvement (VG). For simplicity and effectiveness of presentation, the 23 topics have been grouped into six categories as shown in Table II.

Similarly, improving the students' familiarity with electronic components and datasheets is another objective. The feedback form lists 9 items in this regard. Students are asked to respond how familiar they were with these items at the start of the course (P-poor, M-moderate, H-high, VH-very high), and how much improvement was achieved by the course (No – no improvement, M – marginal, S - significant, VG – very good). Again, for simplicity, these 9 items are classified into 3 categories as shown in Table III.

Along similar lines, progress in assembly and testing skills is assessed. There are 8 items in the feedback form in this regard. These are categorized into 3 groups as shown in Table IV. Confidence in design of simple analog and digital circuits is assessed similarly. The form seeks responses on 10 types of circuits. These are classified into 3 groups here, for simplicity, as shown in Table V.

The feedback data received and analysis of the same are presented in the following section.

B. Data Analysis

This course is offered as an elective to the first year ME (Electrical Engineering). The feedback data received from the students of the first two batches (total 28 in number) are collated and presented in Tables II to V. The response, received from the third batch of 26 students, is not included in the tables, but is consistent with those of the first two batches.

Each entry in the tables indicates the percentage of students who gave a particular response on a particular item. For example, serial number 1 in Table II concerns 'linear op amp circuits and their idealized analysis.' At the start of the course, 10% of the students did not know (D) this topic; 20% of them had a poor understanding (P) of this; another 37% had a fair understanding (F); the understanding was good (G) and very good (VG) for 28% and 5%, respectively. The improvement in the understanding of this topic due to the course is moderate (M) for 20% of the students, significant (S) for another 63% of them, and very good (VG) for the remaining 17%. Nobody has reported 'no improvement' (No) in this regard. The highest response is given in bold, while the second highest is shown italicized (in Tables II to V).

Table II shows that a considerable percentage of students either did not know or had a poor understanding of certain concepts at the start of the course, i.e. at the end of their undergraduate programme. Not more than 6% of the students have reported a very good understanding of any of the topics at the start. On the other hand, roughly 50% of them have indicated either 'did not know' (D) or 'poor' (P) with regard to understanding of four of the topics (serial nos. 2 to 5) at the beginning of the course (i.e. at the end of UG). This needs to be considered seriously in framing the curriculum for Master's programmes, particularly since this has been reported by students with GATE ranks better than 150.

Of the four topics above, particular attention may be drawn to the frequency response of linear dynamic systems (serial no. 4, Table II). While the responses D and P add up to 56%, only 7% have indicated G or VG. This indicates a weak understanding of what frequency response of a linear system is, how to measure it, and how to relate it with the step response of the system. In other words, students find it difficult to correlate s-domain, frequency domain and time domain based studies of linear dynamic systems. The understanding of LTI dynamic systems needs to be strengthened as this is essential for several areas of study.

Regarding improvement in the understanding of various topics, the majority response has been 'significant' (S) for all six topics. Between 60% and 80% students have indicated either significant (S) or very good (VG) improvement in all six topics.

Table III reports the familiarity of students with various electronic components. At the start of the course, majority have had 'moderate' (M) familiarity with discrete components and integrated circuits (ICs). Discrete components include low-wattage resistors, capacitors (disc type), capacitors (other types), diodes, zener diodes and switching transistors. The ICs include op amps, comparators, and logic gates. However, the familiarity with datasheets was 'low' (L) for more than 50% of the students; it was either low (L) or moderate (M) for about 90% of the students. More than 50% of the students have reported significant (S) improvement in familiarity with components and datasheets. More than 80% have indicated either significant (S) or very good (VG) improvement in familiarity with datasheets, which is very important for design engineers.

Table IV presents data on the assembly and testing skills of students. Assembly skills include bread-boarding and soldering. Testing and trouble-shooting skills include testing of individual ICs, awareness of do's and dont's in testing and identifying the trouble spot. Performance evaluation of a circuit includes defining of satisfactory operation of a circuit and finding the limits within which the operation is satisfactory. The initial level of assembly and testing skills was distributed among low (L), moderate (M) and high (H) levels, moderate being the highest (more than 40%). Majority have reported significant (S) progress in all three types of skills. Roughly, 30% have indicated very good (VG) progress in assembly skills.

Table V brings out the confidence levels of students in designing different types of electronic circuits. At the start of the course, the confidence level was low for a majority (40% – 60%) across all types of circuits. It was either low or moderate for 77% to 89% of the students. A majority of students (54% - 65%) have reported a significant (S) improvement in confidence. More than 70% have indicated either significant or very good progress in design of non-linear op amp circuits and comparator circuits. In respect of linear op amp circuits, more than 80% have reported significant or very good improvement in confidence level.

Regarding the overall challenge level of this course, more than 90% of the students regard this as of post-graduate level with the remaining indicating this as an advanced PG course. None of them consider this as a UG course.

C. Future course of action

1. Course content should be improved based on student feedback. Where the initial understanding is good and the improvement reported is moderate, the challenge level of such topics could be increased. If the initial understanding is poor and the improvement reported is moderate, then these topics need to be elucidated further.
2. The impact of this course, if any, on the 24-credit ME projects carried out by the students in the second year could be studied.
3. The course material could be converted into a suitable form such as a workbook and shared with other interested universities and colleges.

V. Conclusion

A laboratory course on electronic circuits is developed for a Master's programme in electrical engineering. The course is reasonably effective as suggested by student feedback. Though the titles of experiments in the course are quite similar to those in the UG level courses, the contents of exercises are substantially different; these take the students through considerable analysis and design. It is significant that about 90% of the students regard this course as a PG level course with the remaining regarding this as an advanced PG course. In a post-graduate power electronics programme, this course can be complemented by similar laboratory courses on power semiconductor devices, magnetic components and digital controllers.

References

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TABLE I

Exercises and learning goals

No	Exercise	Components	Learning goals
1.	Inverting and non-inverting amplifiers	Op amp, resistors	Ideal op amp, dc non-idealities and their compensation, familiarity with op amp datasheets, idealized analysis of linear op amp circuits, input resistance and its measurement, handling of component tolerances
2.	Differential amplifier	Op amp, resistors, capacitors	Analysis of linear op amp circuits, common-mode and differential-mode input resistances and their measurements, handling of component tolerances, nullifying common-mode gain, frequency response and its measurement, power consumption
3.	Active filters and phase shifter	Op amp, resistors, capacitors	Analysis of linear op amp circuits, frequency dependent input impedance and its measurement, improved understanding of linear dynamic systems, correlation between step and frequency responses, measurement of step and frequency responses, types of capacitors
4.	Slew rate and high-frequency response	Op amp, resistors, capacitors	High-frequency non-idealities and limitations of op amp, frequency response of op amp, gain-bandwidth product, familiarity with op amp datasheets
5.	Precision rectifiers	Op amp, resistors, diodes	Half-wave and full-wave precision rectification, linear and non-linear operation of op amp, slew rate, distortion due to slew rate and its mitigation
6.	Comparator circuits	Op amp, comparator, resistors	Distinction between comparator and op amp ICs, non-inverting and inverting comparator circuits, requirement for and provision of hysteresis in comparator circuits, op amp and comparator datasheets
7.	Waveform generators	Op amp, comparator, zener, Schmitt gates	Square wave oscillators based on inverting comparators with hysteresis, square wave and triangle waveform generators, evaluation of limits (amplitude and frequency) for acceptable performance
8.	Wien bridge oscillator	Op amp, resistor, capacitor, diode	Identify and analyze different parts of a circuit, amplifiers with gain limiting, band-pass filter, frequency and step responses of band-pass filter, sine wave generation
9.	Dead-time circuit	Logic gates, Schmitt gates, resistor, capacitor	Requirement of dead-time in a voltage source inverter, circuitry to provide dead-time, ability to design a small circuit
10.	Fault annunciation and protection circuit	Comparator, LED, gates, latches, push-button, manual switch	Protection circuits in a power converter, indication circuit, debouncing circuit, reset pulse generation, ability to design small circuits and to integrate them, testing and trouble-shooting
11.	Mini-project	Any or all of the above	Application and extensions of the concepts learnt, ability to design new circuits, testing and trouble-shooting

TABLE II
Understanding of important topics – Student responses (in percentage)

No.	Topic	Understanding at the start of the course					Improvement due to the course			
		D	P	F	G	VG	No	M	S	VG
1.	Linear op amp circuits and their idealized analysis	10	20	**37**	*28*	5	0	*20*	**63**	17
2.	Non-idealities of op amp and their compensation	22	*26*	**30**	20	2	2	*25*	**56**	17
3.	Input and output resistances / impedances, supply currents, and their measurements	20	**34**	*33*	12	1	2	*27*	**60**	11
4.	Frequency response of linear dynamic systems and its measurement	20	*36*	**37**	7	0	0	*30*	**66**	4
5.	Nonlinear applications of op amp	20	*29*	**34**	15	2	6	17	**59**	*18*
6.	Comparator, logic and protection circuits	11	**32**	*29*	22	6	5	*34*	**52**	9

D – Did not know, P – Poor, F – Fair, G – Good, VG – Very good
No – No improvement, M – Minor improvement, S – Significant improvement, VG – Very good improvement

TABLE III
Familiarity with electronic components and datasheets – Student responses (in percentage)

No.	Item	Familiarity at the start of the course				Improvement due to the course			
		L	M	H	VH	No	M	S	VG
1.	Discrete components	20	**54**	*21*	5	10	*22*	**54**	14
2.	Integrated circuits (ICs)	24	**45**	*29*	2	8	17	**57**	*18*
3.	Datasheets and specifications of ICs	**54**	*37*	9	0	0	17	**52**	*31*

L – Low, M – Moderate, H – High, VH – Very High
No – No improvement, M – Minor improvement, S – Significant improvement, VG – Very good improvement

TABLE IV
Assembly and testing skills – Student responses (in percentage)

No.	Assembly / testing skill	Skill level at the start of the course				Improvement due to the course			
		L	M	H	VH	No	M	S	VG
1.	Assembly skills	*24*	**44**	23	9	11	17	**43**	*29*
2.	Testing and trouble-shooting skills	*38*	**40**	21	1	11	*36*	**46**	7
3.	Performance evaluation of electronic circuits	**43**	*41*	16	0	6	*28*	**57**	9

Abbreviations – as in Table III

TABLE V
Confidence in design of electronic circuits

No.	Electronic circuit	Confidence in design at the start of the course				Improvement due to the course			
		L	M	H	VH	No	M	S	VG
1.	Linear applications of op amp	**41**	*36*	20	3	0	17	**65**	*18*
2.	Nonlinear applications of op amp	**56**	*33*	11	0	2	*26*	**54**	18
3.	Comparator, logic and protection circuits	**58**	*24*	14	4	0	*29*	**61**	10

Abbreviations – as in Table III