# AC 2011-726: TEACHING MEDICAL ELECTRONICS TO BIOMEDICAL ENGINEERING STUDENTS: A PROBLEM ORIENTED APPROACH

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# Teaching Medical Electronics to Biomedical Engineering Students: A Problem Oriented Approach


## Abstract

A significant number of graduates from Biomedical Engineering (BME) enter industry or enroll in graduate programs and are confronted with the challenge of developing electronic medical device prototypes. These prototypes requires the integration of very diverse technical skills including analog and digital electronics, microcontroller hardware and software, telecommunications, power electronics and signal processing. The course investment traditionally used to foster and hone these skills is not practical in a four-year BME program. In order to accommodate the broad nature of the BME curriculum, and still equip BME students with the skills they will need in electronic medical device prototyping, our program implements a problem-oriented, top town approach to teaching medical electronics. Two senior level, co-requisite courses are taught: Microcomputer Based Medical Instrumentation (BME540) and Medical Electronics Laboratory (BME541). The first course (3 Cr) is lecture based, while the second (2 Cr) is a hands-on laboratory.

A problem-oriented methodology has been adapted to help students integrate the diverse and complex topics. The development of a realistic biomedical prototype is both the ultimate goal of the students, as well as a concrete pathway to integrate the many concepts covered in the courses. The teaching methodology incorporates concepts , which students have previous experience with (instrumentation, signal processing, and logic design, for example), and introduces a new set of skills (such as power electronics, microcontrollers, and wireless communication). The course begins by presenting the students with a sample electronic device, which will guide the learning process. The device is broken down into the disparate structures common among all electronic devices, enabling the instructor to address the topics in a broader fashion. To accomplish the concept integration, the lectures and laboratory sessions follow the same logical pathway, mimicking the signal treatment in the device: Analog electronics (instrumentation amplifiers, protection circuits, amplifiers, filters and isolation amplifiers), analog to digital conversion, power supplies (linear, switching and isolated), microcontroller hardware, microcontroller software, data communication and high-level signal display and processing. Professional literature, in the form of application notes and datasheets, are extensively used. The students are trained how to interpret quantitative data presented in the datasheets and how to properly select components based on application. Hardware and software modules were developed for the course; a detailed description of these modules and laboratory sessions will be presented in the paper. During the last 4 weeks of the course, teams of students integrate and test a prototype; specific roles and responsibilities are assigned to each team member based on his/her individual strengths, as observed by the instructors throughout the duration of the course. Typically, the semester culminates in students developing a wireless electrophysiological device, but other devices, such as an optical coherence tomography device are being considered as alternative final projects for future students.

Course objectives are assessed in several ways: by student surveys at the end of the semester, by analysis of the final product and by the associated documentation. BME540/541have been

available for two years with satisfactory results as assessed by student and industry representative evaluations, exit interviews and employment records.

## 1. Introduction

The Biomedical Engineering (BME) industry is fertile ground for BME graduates; this dynamic industry requires more entrepreneurs generating new jobs for our graduates[1]. BME graduates require a broad education having a solid background in science, engineering, and providing the base for innovation. Since medical electronics is one of the fields where BMEs can develop their career, it is important that BMEs who wish to move in this direction, graduate with the technical skills required to develop and test innovations in the form of electronic device prototypes. The course investment used by conventional engineering programs to foster and hone these skills is not practical in a four-year BME program. It is then necessary to efficiently teach a broad spectrum of electronic concepts with a limited course credit impact, in order to enable BMEs to become effective users of electronics technology in the medical field. The challenges in teaching a BME course covering extended material is not unique to medical electronics, it has been reported also in the field of signal processing[2] were new courses intended for BME students are being successfully taught.

In our BME program students choose from three concentrations: mechanical, electrical and pre-medical. Common among the curricula of all three concentrations are courses on programming, basic electrical circuit theory, measurements, medical instrumentation and signal processing. Students in electrical concentration take five additional courses related to electronics: electronics I, logic design, logic design lab, microcomputer based medical instrumentation (BME540) and medical electronics laboratory (BME541). Electronics I, logic design and its laboratory are taught by the electrical and computer engineering (ECE) department while BME540/541 are taught by the BME department. Before the curriculum reform of 2005, electrical concentration students finished their electronics coursework with the electronics II course and a microprocessor course, both taught by the ECE department. The BME department accessed that the students required additional training to close the gap between college and professional practice. The department decided to replace the microprocessor and electronics II courses by the lecture/hands-on course BME540/541 which takes the basic concepts from the two ECE courses and introduces new professional elements of medical electronics in a realistic, industry style approach. BME540 was taught twice, as technical elective (2004 and 2005), and BME540/541 were taught in their new format during spring 2009 (6 students) and 2010 (17 students). The present paper presents the description of the 2010 version of the course.

## 2. Medical Electronics/lab course description

### *2.1 Course Objectives*

The overall objective of the BME540/541 courses is to prepare the electrical concentration BMEs for their professional practice in industry, or graduate studies by closing the gap between theoretical concepts and realistic industry/research applications in the field of medical electronics. Our premise is to present students with course goals that are closer to those presented to an engineer, i.e. develop a fully functional prototype of a bioelectric medical device. In the

"reality" scale proposed by Enderle[3] the course fits in level three where the students solve problems that are structured and researched by faculty, but have multiple solutions and require the integration of many diverse fields. The systems explored in this course include detection, amplification, isolation, protection, analog to digital conversion, power supply, data storage, data communication and signal processing. BME540/541 requires integration of concepts of analog electronics, data acquisition, power supplies, microcontrollers, wired and wireless communications, low-level programming, and signal processing. A challenge of teaching this course is that, in a short time, many diverse topics must be effectively covered without diluting the underlining engineering fundamentals.

*2.2 Course Strategy: a problem oriented approach*

In order to overcome the challenges of teaching BME540/541 courses and achieve the proposed objectives, a problem-oriented approach with hands-on experience is applied. The full development (hardware and software) of a wired/wireless electromyography (EMG) device is used as a pathway to integrate the many concepts. This type of realistic application may require knowledge of many diverse topics, but the required knowledge is compartmentalized purposefully, easing topic integration, and eliminating confusion that might arise if the seemingly disparate topics were presented each in a vacuum. In order to emphasize the interdependency of topics and help students visualize the device as a pathway, lectures and laboratory sessions follow the signal treatment in the device, starting at the electrodes and ending at the display on a remote computer.

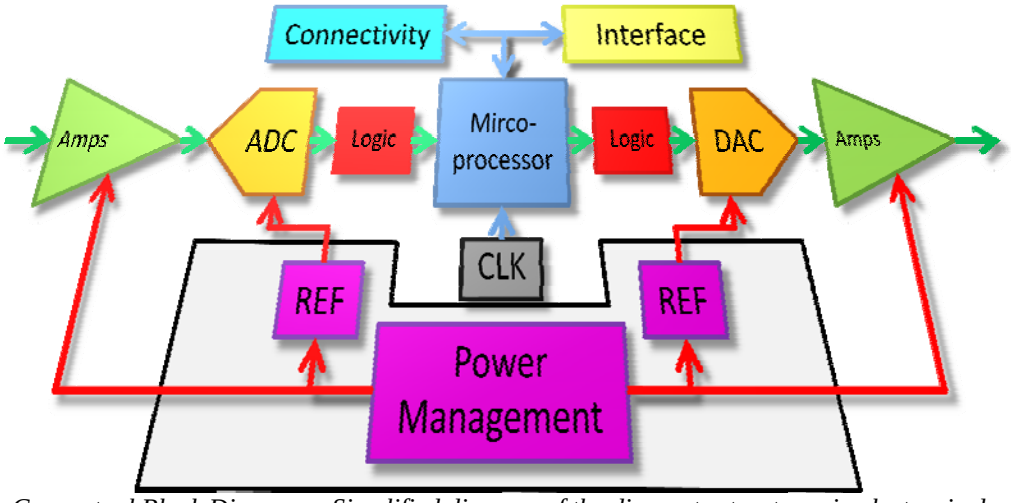


*Figure 1: Conceptual Block Diagram – Simplified diagram of the disparate structures in electronic devices. Lectures and labs are designed around addressing function and implementation of the different blocks. In this example, taken from an actual lab, the focus (as outlined) is Power Electronics.*

Using this idea, the course contains the following main sections: analog electronics, analog to digital conversion, power supplies and microcontrollers. In order to minimize the risk of skipping and/or diluting important engineering fundamental concepts while following this problem-oriented strategy, the instructor addresses topics in a broad fashion. In other words, when following the conceptual device block diagram, the instructor might touch upon a number of examples, from a number of devices rather than just sticking to one specific case. For example, signal isolation is not a critical component of analog processing in battery powered

wireless devices, but it is a crucial topic in numerous other wired medical devices. As such, for each functional structure represented in the pathway various alternative device architectures are presented and explored during the lectures and laboratory sessions.

To achieve good synchronization between the lectures and the laboratory sessions the teaching assistant (TA), in charge of the laboratory session, attends and actively participates in the lectures. Additionally the main instructor attends some laboratory sessions, particularly during the development of the final project. This is done to insure that there is no communication break between the theoretical and hands on portions of the course and to allow for "real-time" feedback.

## 3. Course description

The course begins by presenting the students with an electronic device family that will guide the learning process. Several device architectures (wired, wireless, analog isolated, digital isolated, etc) are discussed and broken down into their disparate structures. The signal pathway is then analyzed and the different topics of the course are introduced. Since this course is the first time most BME students are learning about microprocessors, the history and trends of computer architecture, Moore's law, and data communication are introduced to they might understand the forces which drive the development of electronic devices. After this brief introduction, the topics are developed as explained in the following sections.

### *3.1 Analog Electronics*

Starting from the interface with the physiological system (the electrodes) the analog section introduces all the issues involved in manipulating signals to achieve adequate level and frequency bandwidth at the analog to digital converter (ADC) input. Since the students have learned some of the basic analog electronic concepts in their measurements and instrumentations courses, the topic is familiar to them. In the present course, passive components, operational amplifiers (Op-Amps) and instrumentation amplifiers (IA) are treated using models that are realistic. These "realistic" models do not delve deeply into the solid-state physics involved in their construction, but rather, using more elaborated circuit models involving dynamic linear systems (transfer functions) that explain their overall behavior. Using these elaborated models, the Op-Amp and IA are not single ideal devices but a family of devices having multivariate set of characteristics. Professional literature[4,5,6] , in the form of application notes and datasheets produced by the main component producers is extensively used to understand how the real component characteristics affect the device performance and accommodate students to the information they will deal in their professions. Examples, involving safety issues, noise reduction and real device selection are presented in the lectures.

Table 1. Analog Electronics topics

| Topics | Engineering basic concepts | Realistic elements |
|---|---|---|
| • Operational Amplifiers<br>• Instrumentation Amplifiers<br>• Active filters<br>• Isolation amplifiers | • Negative feedback<br>• Transfer functions<br>• Bandwidth<br>• Displacement currents<br>• Capacitive coupling | • Real characteristics: offset, voltage noise, current noise, impedance, input/output ranges, polar and non polar capacitors<br>• Device selection process<br>• Filter design |

| | | |
|---|---|---|
| • Surge Protection | • Magnetic coupling | • Interference<br>• Data sheet and application notes study |

Table 1, above, shows the different topics covered in the analog electronics section along with the basic engineering concepts and the realistic elements that make the students closer to the professional applications.

*3.2 Analog to digital conversion*

Analog to digital conversion (ADC) is introduced in the ECE linear circuits, BME measurement and BME signal processing courses. These courses do well to establish the mathematical foundations of ADC, but they do not stress the architecture and interface of the real electronic ADC devices. BME540/541 makes an architectural and functional analysis of the most prominent ADC architectures (Flash, SAR, Pipelined and Sigma Delta) along with component selection criteria. Professional literature[7,8] is also heavily used in this section. The MCP3201 (a 12bit SAR ADC with SPI interface) datasheet is fully analyzed in a lecture and used later in the laboratory sessions.

*3.3 Power supplies*

The block diagram of a portable blood gas analyzer[9], presented in Fig. 2, illustrates the extent of the power management block in a typical medical device. The power management block contains a significant percentage of the total number of components in a modern medical device and has strong implications in the device performance and safety. The intelligent selection and use of power supplies is an indispensable skill for any BME developing biomedical device prototypes and becomes one the most challenging topics to teach, because of its apparent extent and complexity.

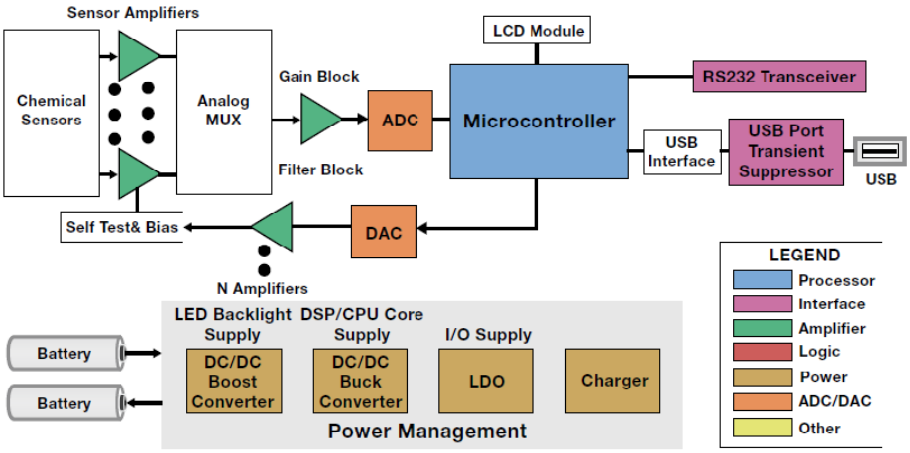


Figure 2. Portable blood gas analyzer block diagram. From "*Medical Applications Guideline*", Texas Instruments 2010. (*Texas instruments do not require authorization to use this information*)

This topic is an excellent opportunity to illustrate how the problem oriented approach is used: 1) using a typical block diagram of a device, the power supply "realistic" specifications are established and analyzed and 2) by using different configurations attempting to fulfill the specifications, the basic concepts and practical considerations are meaningfully introduced. In

the case of power management, specifications for a typical device might include voltage levels; power capacity; safety considerations; weight and size restrictions; ripple requirements; battery life, etc. Using the application example in mind, learning has a clear goal and the study of different standard power supply configurations is a natural consequence of the necessity. To become a smart user of the technology it is assumed that the students have to be able to point out the advantages and disadvantages of the different alternative solutions and make an informed selection of modules available in the market. The power supply study is then limited to: 1)the understanding of the basic architectures[10,11] using circuit analysis; 2) the execution of computer simulations (Matlab) of approximated circuit models and 3) the analysis (theoretical and hands-on) of a representative set of commercially available power supply modules. Table II, shows the different topics addressed in the power management module along with the basic engineering concepts and realistic elements considered.

Table II. Power supplies topic

| Topics | Basic engineering concepts | Realistic elements |
|---|---|---|
| • Batteries<br>• Linear regulation<br>• Charge pumps<br>• Boost converters<br>• Buck converters<br>• Isolation amplifiers | • Electrical Energy<br>• Electrical Power<br>• Efficiency<br>• Capacitance, Inductance<br>• Basic switching circuits<br>• Feedback | • High frequency effects on passive components<br>• Device selection process<br>• EMI<br>• Power quality<br>• Power management module selection<br>• Data sheet and application notes study<br>• Isolation |

Another aspect of the problem-oriented method regards the order in which the topics are presented to the students: instead of presenting an elaborated, "optimal" solution from the beginning, we experimented with a naïf approach where the instructor, purposefully, proposes an "easy" initial solution. The proposed solution is then systematically validated using the specifications to quantify its advantages and disadvantages. The instructor repeats the process with many other possible solutions, increasing in complexity until all the planned topics are covered. In the power supply module, the instructor proposes the use of linear regulators (conventional and LDO) as initial solution and, using efficiency computations, explains why switching power supplies are a better alternative. While covering switching power supplies, the charge pump, boost and buck architectures are analyzed.

*3.4 Microcontrollers*

We acknowledge that it is not possible to obtain a deep knowledge of the newest microcontroller architecture with the time limitation imposed by a course including so many topics. However, we assume that it is possible to teach the basic operational concepts, interface and low level programming of a microcontroller, providing the foundations to BMEs to develop well performing medical electronic device prototypes. Once the basic concepts are known, specific architectures can be applied to the development of medical devices when modern development tools are used. To achieve the course goals, the basic microcontroller concepts were taught using the "classic" Intel 8051 architecture while the popular Arduino development system[12] was introduced later to show a higher level, more powerful, architecture.

The microcontroller section includes the following topics: program memory, data memory, clock circuits, reset circuits, digital input/output, timers and counters, interrupts, ADC interface, serial communications and finite state machine programming. The hardware of the 8051 architecture was fully developed and all the programming was done in C language. An educational board, described in the laboratory session, was developed for this course.

## 4. The Laboratory sessions

At the beginning of the semester, students are familiarized with the equipment and materials they will be using in the lab, as well as lab safety guidelines and procedures. Typically, in the introductory session students are also grouped with a lab partner whom they will work with for the remainder of the semester. Lab sessions are organized to run parallel with the concepts discussed in the course lectures in order to present practical experience to complement theory as soon as possible. Prior to each lab session, a lab guide is posted online which the students are expected to print out and familiarize themselves with before coming to the lab session. Contained within each lab guide are: an outline of the objectives set for that particular lab session, procedures for the experiments they will be performing that week, and problems pertaining to the lab which the students are expected to finish within the allotted laboratory time. Included in each lab is a flowchart representing the components of a generalized electronic device. In order to aid the learning process, the sections of the flowchart that pertain to the current lab are highlighted, and the significance of the lab exercises to the grander scheme of the device is explained. For instance, the Power Electronics lab opens with the aforementioned flowchart with the power management and reference generation blocks highlighted. Following this is a brief explanation of the role of power electronics in an electronic device and several 'real world' scenarios were power electronics are used. This is done in order to always keep the 'bigger picture' in the mind of the students, and so that they do not become overwhelmed or lost by the seemingly disparate material from one lab session to the next. Table III shows the topics of the lab sessions over the semester.

Table III. Laboratory sessions

| Session | Topic | Description |
|---|---|---|
| 1 | Introductory Session | Overview, Introduction to Equipment and Safety Procedures. |
| 2 | Introduction to PCB design | Familiarize students with the fundamentals of taking a prototype circuit to a printed circuit board (PCB) such as would be found in a commercial electronic device. Introduce students to two forms of commercial PCB design software: ExpressPCB and Eagle. |
| 3-5 | Analog Signal Processing | Review signal manipulation using Operational Amplifiers (Opamps) in various configurations to create Inverting amplifiers, Non-Inverting Amplifiers, Summing Amplifiers, Instrumentation Amplifiers, Integrators, Differentiators, Comparators and Analog Filters. Response characteristics of each circuit are examined and PCB designs are created for each circuit. |
| 6 | Power Circuits and Isolation | Generate various DC potentials from both AC and DC sources to meet the various power requirements of different components in a potential design. Study efficiency values for different power circuits and learn which are appropriate for different applications, such as power requirements for a portable device, versus one that can be plugged in. Test isolation circuits to ensure that prototype medical devices will be safe to use on subjects. |
| 7-9 | Introduction to the Microcontroller | Learning about the microcontroller bridges the gap between hardware implementations and high level programming languages. Students are familiarized with the features and functions of several basic microcontrollers and |

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|---|---|---|
| | | through a number of exercises, learn to code the microcontroller to increase the sophistication of their device prototypes by manipulating both software and hardware. |

For the early lab sessions, students are asked to construct circuits which approximate the functions of the various blocks in *Figure 1*. All circuits are constructed using discrete analog components on breadboards. Both nodal analysis and direct observation with oscilloscopes is to monitor signal treatment at each block. Students are asked to anticipate how changing certain discrete components in their circuits will affect the output of the circuit, calculate the changes using theory learned in class, and then verify their calculations by actually changing said components. This is done in order to make the potentially tedious task of constructing circuits from a schematic a more active experience and familiarize students with the role and importance of each individual component, as well as give immediate feedback to the students. All observations are collected and logged in a lab report after each session.

In later labs, focus shifts to the microcontroller, specifically the 8051 model microcontroller. Lab work shifts from building physical circuits to writing segments of code. Many students find programming portions of the course to be less immediately rewarding if they are only manipulating digital values internal to the chip. In order to help ease the shift, as well and give students immediate physical feedback, the instructors for the class built a specially designed test board. Each board was fitted with a port where the AT89C8051 microcontroller could be plugged into after programming. Included on the board were a number of pieces of hardware, (such as a RGB LED) which the students could immediately start to manipulate after writing only a few lines of code. Other elements were: two SPI interface 12 bits analog to digital converters and a serial port RS232 transceiver used to connect the board to a PC to test communication protocols.

## 5. The final Project

During the last four/five weeks of the courses, the students develop a prototype while working in teams containing up to four students. The project has two phases: the design phase and the implementation/testing phase. Once the project statement is given, the students have two weeks to make a detailed design of their prototype and deliver a formal design report to the instructor. The instructor provides feedback about the design and must give his approval before the students are allowed to move into the implementation phase. If the instructor finds “design flaws”, he requests modifications to the team and they are allowed a period of time to alter their proposal. Normally this design feedback process takes three to four days. During the implementation phase, the students assemble and integrate the different modules of their prototype and upon completion, deliver a final report and oral presentation to the instructor and the TA. The allotted time for the project looks very short, but the project builds upon many different modules already developed during the laboratory sessions, and the design verification process carried out prior to the implementation phase improves the likelihood of achieving successful project goals in a timely matter.

During the spring 2010 course, the students developed a wired/wireless EMG recording device having some basic analysis and display functions on a PC computer. The problem statement included the following specifications for the device:

- *Input Range: ±4mV*
- *Power supply: Single 9V battery.*
- *Bandwidth (-3dB): 10Hz-300Hz*
- *Gain: 0.5V/mV*
- *Analog Isolation: Yes*
- *Sampling Rate: 720 sps*
- *Sampling Bits: 10 or 12 bits*
- *Communication: Serial port: 38.4 Kbps. (Direct, Bluetooth or USB serial adapter)*
- *Local Display: RGB LED*
- *Communication Protocol: custom including wakeup, start acquisition and stop acquisition functions*
- *PC Software platform: Matlab or Labview*
- *PC Display: 10s of raw EMG plus envelope*
- *Data Processing: Notch filter plus rectification and low-pass filtering.*

The students were asked to follow a top-down design methodology to improve their skill of breaking large complex problems into small ones. Even if it was a team project, the instructor and TA assigned individual students to specific responsibilities: 1) analog electronics; 2) power supplies and isolation, 3) microcontroller programming and 4) high-level PC programming. The assignment of roles was based on the ability and/or interest the student showed during the laboratory sessions. In the design report students were asked to perform computations/simulation to predict and document the behavior of the circuits when synthetic (signal generator) and real signals were applied to the device. This intensive design/simulation work improved the quality of the designs, and reduced the assembling and validation activities.

**6.0 Course Assessment**

The students assessed the course using two mechanisms: 1) end of class surveys, applied independently to the lecture and the laboratory and 2) students exit interview with the department chair.

*6.1 Class surveys*

At the end the semester the students are invited to fill out a three part, anonymous evaluation of the course. The first part asks for a quantitative evaluation of the instructor, the second deals with an evaluation of the fairness of the course grades, and in the third part, the students write candid comments about the course content, the instructor, and a general advice to new students. These candid responses provide valuable feedback for continuous improvement. All graduating students complete an exit survey at the end of the last semester before graduation.

Seventeen out of the eighteen BME540 students participated in the class survey assessment providing an overall positive feedback of the course (Overall mean 3.9/5) in the quantitative section. The aspects the students showed more satisfaction were: 1) the close

interaction instructor/students (16/17) and 2) the fact the course challenge them to think (15/17). The students showed less satisfaction with the course material presentation (10/17 positive), the exams and assignments (11/17 positive). The qualitative student feedback gives information that is more detailed about the specific aspects than can be improved; table IV, below presents a summary of the students feedback about the course improvement opportunities:

Table IV. BME540 student candid feedback

| Topic | Nbr | Comments |
|---|---|---|
| Course content | 3 | The students appreciate the extended content of the course covering that many topics. One student sees how the material will help to completely design a medical device and, finally a student questions if the course is too ambitious. |
| Course material | 2 | One student express that the material is somewhat hard to grasp and another student considers that the material was presented fairly at a good pace. |
| Exams, homework | 4 | The students addressing this point were unsatisfied; they consider not enough feedback is provided during the semester and homework |
| Link lecture-laboratory | 2 | The students agree that there is a degree of coordination between the lecture and the laboratory but they think is necessary to have more. |

The subject that elicited the most comments from the students was related to exams and homework: students felt the instructor did not provided enough homework and feedback during the semester. We think these comments reflect the fact that practice exercises and homework load were heavily shifted to the laboratory session, while the main exams (midterm and final exam) were given in the lecture section. It seems that the communication between the lecture and laboratory did not work as well as expected (see comments in the table). While the content and pace of the laboratory session was influenced by the lecture session, there was no feedback in the other direction, with the lab influencing the lecture. Allowing for two ways flow of information between lab and lecture, and having both session adapt to each other in real time over the course of the semester might address some of the students concerns. Regarding the course content, students acknowledge and appreciate the broad coverage of the course, but one questions if it is too ambitious. Finally, students also report difficulties in the materials used and, in the manner it was presented (quantitative section). Having too many diverse sources of information, mostly professional literature, constitutes an extra-effort for the students but, also, prepares them for the type of information they will find in their professional practice.

*6.2 Laboratory surveys*

Sixteen students were enrolled in the BME541 lab section, and of the sixteen, fifteen students participated in the assessment survey. Students quantitative assessment of the laboratory section rated slightly higher, with an overall mean score of 4.5/5. Student responses with regards to both course items and instructor items were predominately positive, (14/15 positive for instructor items, and 13/15 positive for course items). Qualitative feedback is summarized in table V.

Table V. BME541 student candid feedback

| Topic | Nbr | Comments |
|---|---|---|
| Course content | 5 | Three students address their satisfaction with the courses and all agree giving a positive feedback. Two students appreciate the extended content of the course covering that many topics. One student sees how the material can be applied in a future product development. One student highlights how the course helped |

| | | |
|---|---|---|
| | | him/her better understand the integration software and hardware. One student suggests to in the main lecture similar block diagrams to the ones used in the lab to help him make a good integration of concepts. Finally, one student ask for more circuits. |
| Link lecture-laboratory | 3 | The students (3) states that the laboratory was useful understanding the material. Moreover, they estimate that they learn more in the laboratory than in the lecture. |
| Recommendations to peers | 5 | The students (5) recommend the class to their peers. One student considers this class challenging but worth it. The reason the students give to recommend the course is that they learn a lot (3); specifically a student states that he/she learned how to design a complete medical device. |

*6.3 Exit interviews*

All outgoing graduates from our BME program are invited to participate in an exit interview as part of their graduation requirement. The Department Chairman administers these exit surveys, during which a number of specific questions are asked. In these interviews, students express their thoughts on the strengths and weaknesses of the courses, faculty, and curriculum as a whole. These interviews, in conjunction with the course surveys, are tools that the department uses to guide academic improvements in. At the end of the Spring semester of 2009, several BME students within the electrical concentration graduated and provided valuable feedback about the medical electronics course. Eight students went through the interview process and five of them spontaneously mention this class in the interview, expressing satisfaction. Two students recognized the contribution of the instructor and the teaching assistant.

## 7.0 Discussion and improvement opportunities

This paper presents the experiences of teaching a course paradigm that is becoming more and more prevalent in BME: A broad range of applied engineering topics, covered in a short time; the expectation is to train BMEs to be smart users of electronics technology by understanding the underlining engineering principles while simultaneously acquiring hands-on experience with the technology. The problem-oriented methodology with a lecture/hands-on approach seems to be a good way to achieve these goals. By providing students with concrete implementations of the engineering concepts they are to learn, in the context of devices they are all familiar with, a framework for the concepts is built up, facilitating the learning process.
Several opportunities exist to further improve the course outline proposed above. As the course covers a wide range of topics, a textbook to supplement class notes and handouts would undoubtedly be beneficial. Ideally, the text would present engineering principles, include links to professional literature and provide software examples. An appropriate text that meets these guidelines is currently being looked for. Another area for improvement is in course assessment. While the final project serves as an objective measure of the skills learned by the students over the course, roles and expectations for the project differ slightly from student to student. As such, there exists the potential for gaps in objective assessment, as no one student is responsible for the entirety of the project. Better objective measures, such as a pre-and-post course skills assessment, can be implemented in the future to address this shortcoming. Additionally, an even closer interaction between lecture and laboratory seems to be required; perhaps only one course, in a mixed lecture-lab classroom should be implemented. As indicated by the student feedback

and by design the presented course does well to help closes the gap between college education and BME professional practice.

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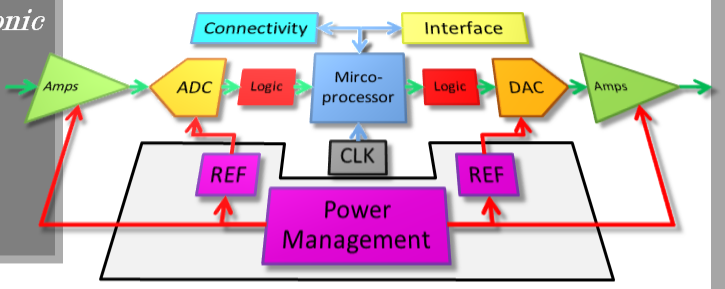
## Appendix 1: Power Circuits laboratory Guide

BME 541
*Medical Electronic Systems*

Lab 6
*POWER CIRCUITS*




**Introduction**

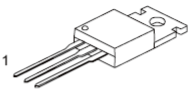
Most, if not all electronic devices require some kind of power circuitry in order to convert electricity, be it from an outlet or battery, into the useable format for the device in question. In some cases, these circuits transform the AC signal from the wall outlet into a single, or sometimes multiple, DC voltage values. Other times, power circuits will be used to manage the battery life of a portable device.

In today's lab you will examine and measure the efficiency of three power circuits used in portable electronic devices

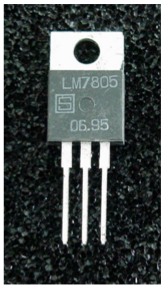
### Part I
### Linear Regulator - LM7805

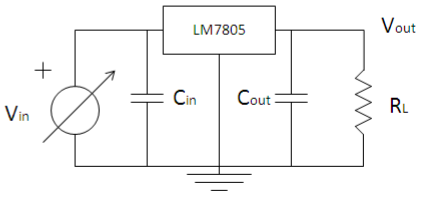
**Procedure**

- Set up the circuit in the bottom right
- Select load resistor such that the maximum output current will be 100mA
- Cin = 0.33 µF Cout = 0.1 µF
- Vary the Input Voltage from 0V to 20V in increments of 2.5 V
- At each increment, note the following values
  - Vin
  - Vout
  - Iin
  - Vgap
- Calculate Pin, Pout and Efficiency from the above values and collect all data in a table.
- Graph Vout vs. Vin, Efficiency Vs. Vin




1:Input 2:GND 3:Output

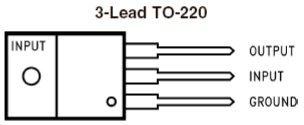


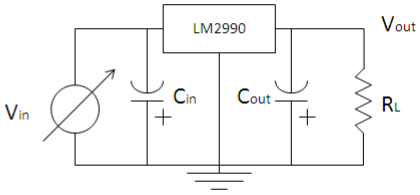
## Part II
## LDO Regulator – LM2990

**Procedure**

- Set up the circuit in the bottom right
- Select load resistor such that the maximum output current will be 100mA
- Cin = 10 µF Cout = 10 µF
- Vary the Input Voltage from 0V to -20V in increments of 2.5 V
- At each increment, note the following values
  - Vin
  - Vout
  - Iin
  - Vgap
- Calculate Pin, Pout and Efficiency from the above values and collect all data in a table.
- Graph Vout vs. Vin, Efficiency vs. Vin



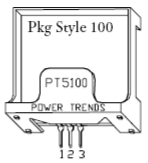

**Pertinent Specifications**
Input Voltage Range: 0.3V to -26V

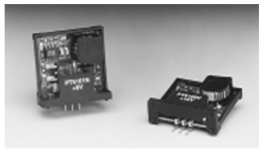



## Part III
## Switching Power Supply
## PT5101

**Procedure**

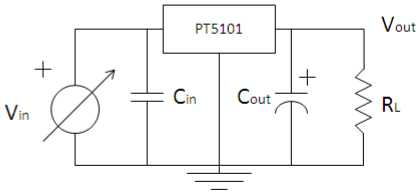
- Set up the circuit in the bottom right
- Get a HIGH wattage resistor from the instructor for the load resistance
- Cin = 1 µF Cout = 100 µF
- Vary the Input Voltage from 9V to 20V in increments of 4 V
- At each increment, note the following values
  - Vin
  - Vout
  - Iin
  - Vgap
  - Vripple
- Calculate Pin, Pout and Efficiency from the above values and collect all data in a table.
- Graph Efficiency Vs. Input Voltage



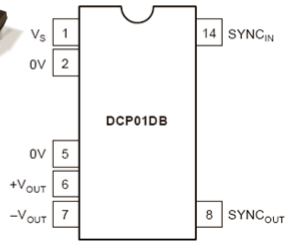



| Pin | Function |
|---|---|
| 1 | $V_{in}$ |
| 2 | GND |
| 3 | $V_{out}$ |

**Pertinent Specifications**
Input Voltage Range: 9V to 38V



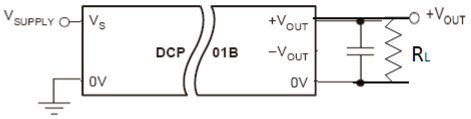
## Part IV a
## 1W Isolated DC/DC converter




### Procedure

- Set up the circuit in the bottom right
- Apply 5 Volts to Vsupply
- Cout = 1 µF
- Vary the Load resistors for 5 conditions
  - $I_{100\%}$
  - $I_{75\%}$
  - $I_{50\%}$
  - $I_{25\%}$
  - $I_{10\%}$

(Where $I_{100\%}$ is the maximum load current, i.e. the current when you are supplying 0.5 W)

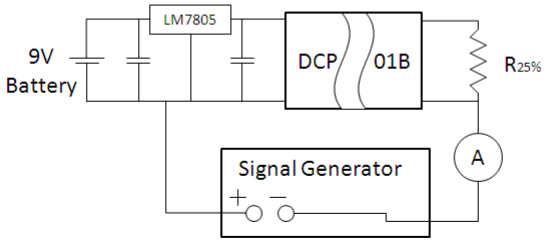



- Measure Vout, Vripple, Ripple Frequency and Efficiency for each load resistance.
- Graph Vout vs. % Load, Vripple vs. % Load and Efficiency vs. % Load.

## Part IV b
## Testing Isolation

### Procedure

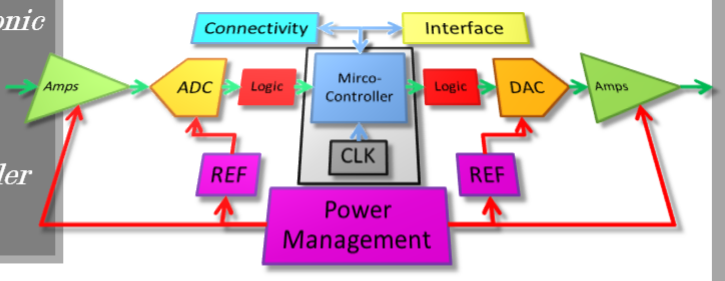
- One of the main uses of a Isolation amplifier is to ensure the safety of a person connected to a device.
- To test this you will connect a nine volt battery to the LM7805 as shown, and then connect to the output of the isolation circuit at 25% load.
- Place a function generator across the two grounds of the isolation circuit with a 60 Hz sine wave at max amplitude.
- Connect the DMM as shown to measure the current after isolation.
- "Safe" is a current less than 10 µF.
- Can this isolation circuit be considered "Safe"?



## Appendix 2: Microcontrollers laboratory Guide

BME 541
*Medical Electronic Systems*

Lab 7
*Micro-Controller Lab*




### Introduction

The microcontroller is the heart and soul of any portable electronic device. What might take a dozen ICs to implement without a microcontroller can become as trivial as a few lines of code with one.

In the following lab sessions you will write programs of ever increasing complexity for the 8051 microcontroller. The programs will then be loaded onto the 8051 with the Python programmer, and the code will be confirmed using a Microcontroller test board.

## Introduction

### Procedure

- The following exercises will differ greatly from the previous labs in this class. In these exercises you will utilize two programs:
  - ProView, by Franklin Software, to code and compile for the microcontroller
  - Phyton software, and the Phyton universal programmer to load your code onto the microcontroller.
- After programming the microcontroller, you will use a specially designed test board to verify that your programs are working properly.

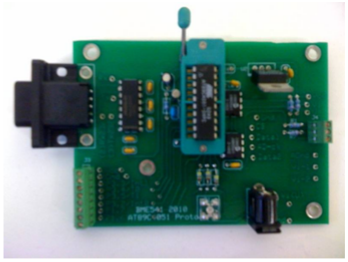
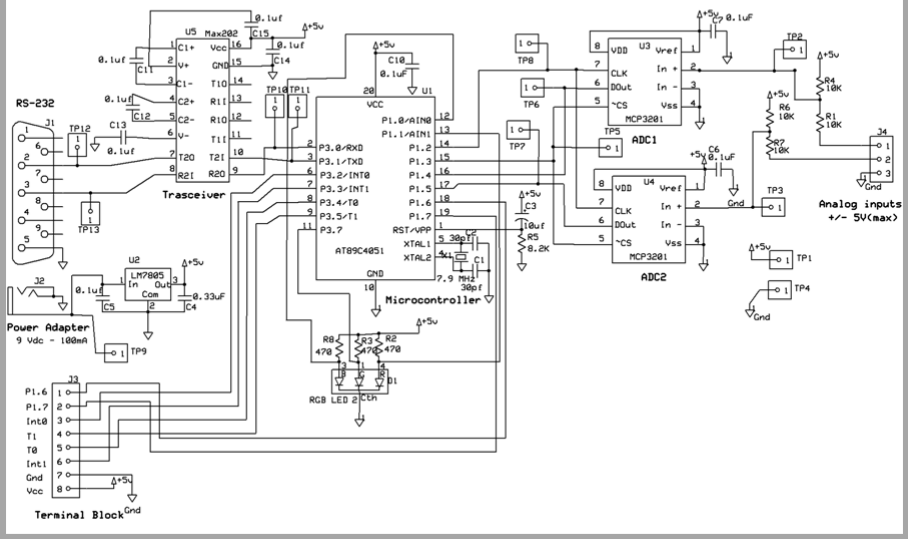


*Fig. 1 – 8051 Test board*


*Fig. 2 – Phyton Universal Programmer.*

## Test Board Schematic




## Part I
## Generating a 1 kHz Square Wave

### Procedure

- Using the I/O pin P1.6 of the microcontroller, generate a 1 kHz square wave signal. (the microcontroller main clock frequency is 11.059 MHz).
- Have the program you write run continuously.
- Once you have error checked and complied the code. Debug your program and load it onto the microcontroller.
- Get an screenshot of the trace window showing the program timing.
- Connect the micro controller into the test board.
- Using the Oscilloscope, verify the waveform and the frequency.
- Capture the output waveform for your lab report using the DSO3000.

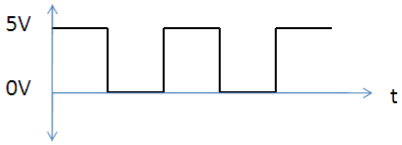



*Fig. 1 – Image of the illusive square wave, as it is seen in the wild.*

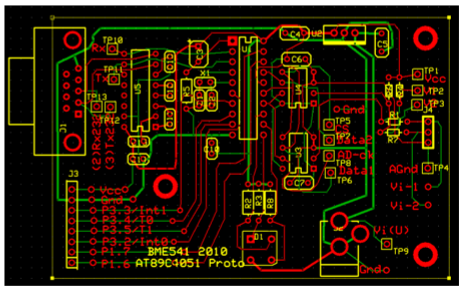



*Fig. 2 – Schematic of the test board.*

# Part II
# Driving an external load.

## Procedure

- As you saw in the previous section, the microcontroller can be used to generate signals to control external circuitry. These loads can be anything from an ADC to a servo or stepper motor.
- Built into the test board is a simple electrical load, an RGB LED. In this section you will write a program to drive that led.
- Write a program that will cycle which of the 3 LEDs within the RGB LED is on, Red, blue, green, once every second.
- Now try to show your school spirit and try to display Green, Orange and White. Vary the on time of each color, say one second, 2 seconds and half a second.

*Fig. 1 – Physical Dimensions of RGB LED*

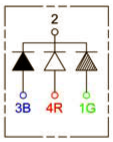
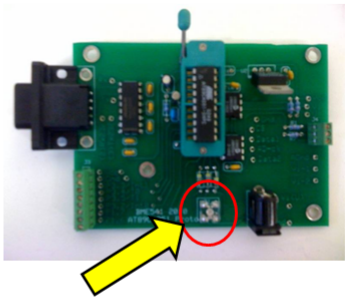



*Fig. 2 – Schematic Form of RGB LED*



# Part III
# Reading from the ADC

## Procedure

- In the previous section you had the microcontroller essentially generate a "clock" signal. This signal can be used to drive other timed circuits in your design.
- The test board designed for you is outfitted with two analog to digital converters, in particular the MCP3201.
- Write a function that will read a sample from the ADC, and store it in an integer in memory.
- Read an analog voltage between 0 – 5V.
- Have the test board display one of 5 different colors based on the input analog voltage.
- You will program the microcontroller to generate the required CLK for the ADC, as well as the chip select line.
- **Once you have this working elaborate your code to save the reading from the ADC into an integer in memory, this will come into play later.**

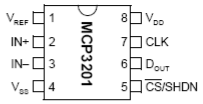



*Fig. 1 – Pin layout for the MCP3201*

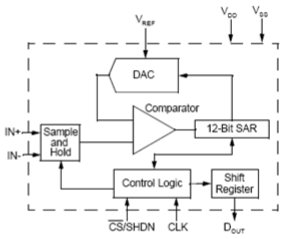



*Fig. 2 – Functional Block Diagram for the MCP3201. (Note the CLK line)*

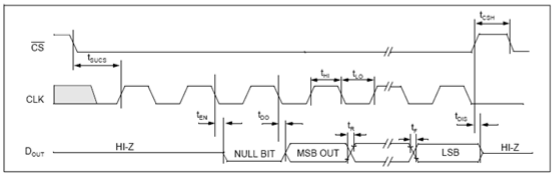



*Fig. 3 – (Left) The function of the MCP3201. You will provide the clock and chip select using outputs of the 8051. Using inputs you will read in the bits one at a time, and store them in memory.*

# Part IV
# Writing from the Serial Port

## Procedure

- Connect the serial port from the Microcontroller test board to a PC.
- Open up the Hyperterminal in Windows. Configure the hyperterminal for a baud rate of 9600 bps, 1 stop bit, non parity, no flow control.
- This window will allow the PC and microcontroller to communicate.
- Configure Timer 1 in mode 2 and set the reload value to achieve a baud rate of 9.6k.
- Configure the serial port and write a program to transmit the following ascii sequence. ('00', '01', '02'…'98', '99' and repeat) *see the ascii table to the right for the corresponding Hex values.
- Remember, SBUF only accepts one byte at a time. So you will need two cascaded 'char' to achieve the above sequence.
- Once you complete this task, adapt your code to send at a defined speed. In this case, 240 codes/sec, meaning 2 bytes, every 1/240 seconds.

| HEX | Corresponding Ascii Character |
|---|---|
| 30 | 0 |
| 31 | 1 |
| 32 | 2 |
| 33 | 3 |
| 34 | 4 |
| 35 | 5 |
| 36 | 6 |
| 37 | 7 |
| 38 | 8 |
| 39 | 9 |

# Part V
# Reading from the Serial Port

## Procedure

- Now we will have the microprocessor deal with incoming signal from the serial port.
- In Part III you read a value from the ADC and stored it in memory.
- We will now adapt that code to send this value to the PC.
- To request a sample from the ADC, the user will press '0' on the keyboard.
- Upon pressing the '0' key, the value will be sent to the hyper terminal.
- Recall that this value was of type 'int', in other words 2 bytes long. (You MUST send the MSB first, followed by the LSB.)
- Once you have finished the above, write a program that will have the RGB LED display different colors based on which number is pressed on the keyboard!