AC 2009-78: AM RADIO CONSTRUCTION: A JUNIOR-LEVEL ELECTRICAL ENGINEERING CORE LABORATORY

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AM Radio Construction – A Junior Level Electrical Engineering Core Laboratory

Background

The junior level core laboratories at our university are not tied to specific technical areas or classes. Instead, the junior labs are designed to be multi-disciplinary, integrating concepts throughout electrical engineering. Such an approach has a number of advantages[1-4], one being that students can more readily appreciate the interrelation between electrical engineering sub disciplines. In addition to the technical content, the core laboratories also develop our students' teaming and communications skills (both oral and written). Laboratory course structure throughout the junior year consists of a Monday lecture, followed by a 2-hour lab period later in the week.

For over a decade, in the first junior level laboratory our Electrical Engineering students have assembled, tested and analyzed an AM/FM radio using a commercially available kit. A primary goal for this course is for students to understand basic concepts from electronics, electromagnetics, and signals and systems along with how these concepts are integrated to realize a working radio. Students studied schematics, received training in how to solder, modeled portions of the circuit with PSpice, and studied operation of a variety of devices including diodes, transistors, and antennas. Towards the end of the semester, students were tasked with a design project. This tended to be the students' favorite part of the course, being somewhat more involved than the kit radio.

Almost every student's radio worked. However, a common complaint from end-of-semester student surveys is that the course had a strong "solder-by-the-numbers" aspect and that students did not always understand what they were doing. There was general dissatisfaction with the PSpice assignments, as the circuit was too complicated to simulate with the student version so simplified portions were studied instead. These shortcomings, along with recent problems with radio kit quality and new safety restrictions on soldering, has led to redesign of the lab.

New Approach: AM Radio on Solderless Breadboard

In Fall 2008, we embarked on an improved lab experience: construction of an AM heterodyne radio on a solderless breadboard. The overall radio is introduced as a block diagram consisting of an antenna, mixer, oscillator (LO), bandpass filter (BPF), intermediate frequency (IF) amplifier, detector (det), audio (Aud) amplifier and speaker (see Figure 1 block diagram). Here, the antenna-received amplitude modulated RF signal is mixed with a tunable oscillator frequency. The output of the mixer is filtered to leave behind only the intermediate (or difference) frequency, which is then amplified. This amplitude modulated IF signal is passed through a detector to extract the audio signal. The audio signal is then amplified and passed to the speaker.

The weekly progression for the trial run of the AM radio lab is shown in Table 1. Prior to construction of the radio, students spent a lab session getting reacquainted with the laboratory

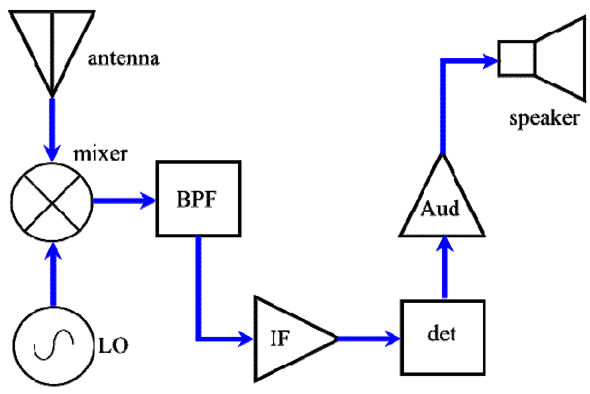

Figure 1: Generic AM radio

Table 1: Timeline for first offering of the AM radio lab

week	Lab
1	Test & measurement
2-3	Common emitter amplifier
4-5	Audio amplifier
6-7	AM detector
8-9	IF amplifier
10	Mixer/Band pass filter
11	Antenna
12-13	Local oscillator
14	Demonstrate working radio

equipment (some of the equipment was familiar to them, but not all). This lab included the generation and measurement of sine waves and amplitude modulated waves. In the second and third labs, the common-emitter amplifier was studied. Not all students had yet taken the analog electronics course where common-emitter amplifiers are covered, so background on this type of device was supplied through the common Monday lecture and notes in the lab manual. A detailed, step-by-step PSpice assignment took them through construction and simulation of the CE amplifier. In addition to its "normal" operation, students saw how well the amplifier worked when it was biased in saturation, when the transistor was flipped (a BJT is not a symmetrical device, but will still weakly amplify), and when it was subjected to a large input signal (resulting in a distorted output). Then, the breadboard version was studied and tested. Students learned important amplifier concepts such as gain and bandwidth, and developed additional competence in using the laboratory equipment.

Students were now ready to start on their radio, beginning with the audio amplifier block. A push-pull amplifier, as shown in Figure 2, was studied, analyzed, constructed and tested. Different amplifier classes were discussed and compared, including the class-A common-emitter amplifier students had previously studied and the more power-efficient class-AB push-pull amp. The speaker was attached to the amplifier (students soldered wires to the speaker), and the amplifier was tested with an audio frequency input. Many students took this opportunity to conduct

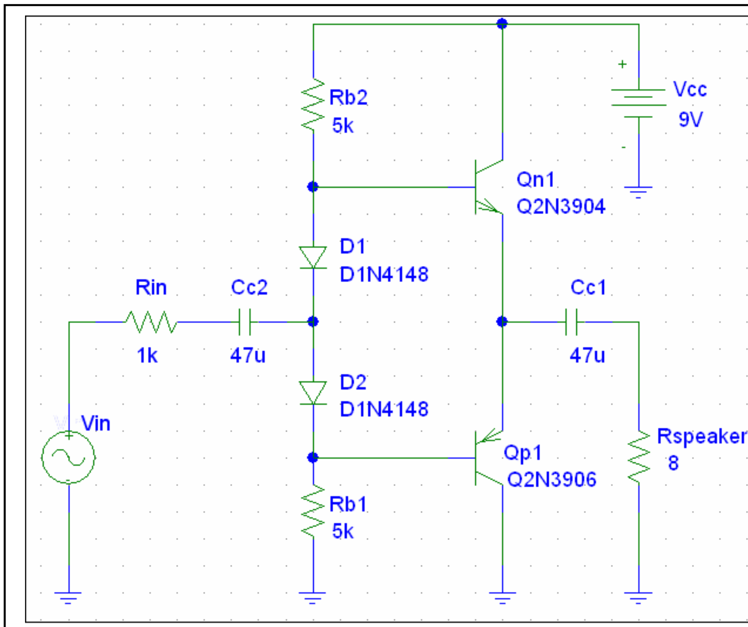

Figure 2: PSpice version of the class-AB push-pull amplifier.

an impromptu hearing test.

The radio was further developed in the weeks to follow. The AM detector, IF amplifier, mixer and bandpass filter were described in lecture and the lab manual, studied with PSpice, breadboarded and measured (see Figures 3 & 4). Sound from the speaker indicated success as blocks were added. The lab saw a change of pace with the design and construction of a square-loop antenna. Here students begin working in teams of 2 or 3. Many teams used a pizza box (Figure 5) as the antenna frame (such boxes are readily available on most college campuses). A few students were able to receive a radio station, albeit very weakly. Some improvement was heard when radios were taken outside. No one achieved a heterodyne AM radio, and only one team of two students went on to successfully construct the oscillator.

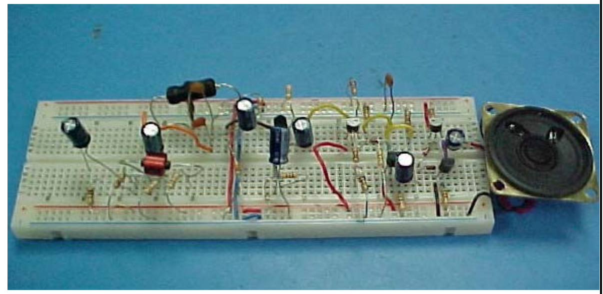

Figure 3: One student's version of the radio, without the oscillator, mixer and antenna.

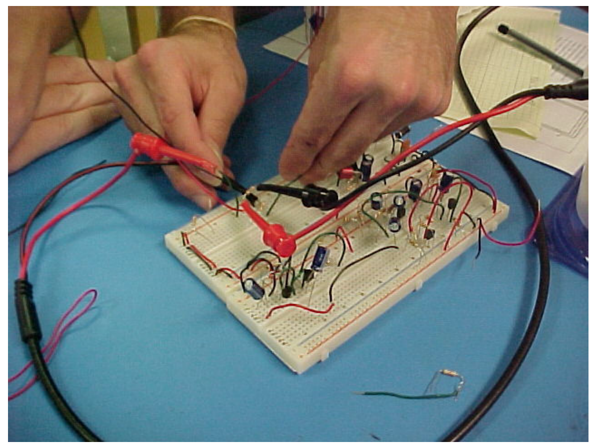

Figure 4: Testing a portion of the radio

Figure 5: Square-loop antenna realized on a pizza box.

Student Survey

It was anticipated that this new version of the radio lab would be a significant improvement over the old one. A survey instrument was given to the students at the end of the semester to gauge our success.

In part 1 of the survey (Table 2), students were asked about the different parts of the AM radio. They were to indicate how well they understood the part and how important they thought the part was to the overall radio. They were also to indicate their satisfaction with how much time we, as a class, spent discussing the part and how much time they spent, in or out of lab, working on it. Most of the success in the radio occurred during the earlier part of the course. They considered their understanding and the time we spent discussing the material highest for these parts. As we ran into difficulty, in particular with getting the radio to work with the mixer and antenna in place, satisfaction dropped. Most students didn't build the oscillator so students cited this as the topic of lowest understanding, least discussion, and least time working on. Students did, however, feel they had a pretty good understanding of how the AM radio works.

Table 2: Average results for part 1 of survey (30 students)

The AM Radio	**Your Understanding** 1 = none 5 = complete	**Topic importance** 1 = none 5 = a lot	**Time spent discussing** 1 = too little 3 = just right 5 = too much	**Time spent working on** 1 = too little 3 = just right 5 = too much
1. audio amplifier	3.9	4.1	3.0	2.9
2. AM detector	4.1	4.2	3.0	3.1
3. IF amplifier	3.9	3.9	3.0	3.1
4. Filter	4.2	3.9	2.9	3.0
5. Mixer	3.3	3.6	2.7	2.9
6. Antenna	3.5	4.2	2.7	3.2
7. Oscillator	2.9	3.3	2.4	2.3
8. Overall AM radio	3.8	4.4	2.8	3.2

Table 3: Average results for part 2 of survey (30 students)

Additional Topics	**Your skill or ability** 1 = none 5 = expert	**Topic importance** 1 = none 5 = a lot	**Time spent discussing** 1 = too little 3 = just right 5 = too much	**Time spent working on** 1 = too little 3 = just right 5 = too much
1. PSpice	3.6	4.3	2.8	3.2
2. MATLAB	3.1	3.7	2.3	2.5
3. Technical Writing	3.5	3.9	2.9	3.0
4. Oral Presentations	3.6	3.7	2.6	2.9

Part 2 of the survey was for assessment of some of the auxiliary aspects of the lab. Students made use of PSpice throughout the semester, used MATLAB to evaluate antenna design formulas, turned in a technical memo every other Monday, and delivered an oral presentation at their lab section meeting at the semesters' end. Considering PSpice, students used this tool far more than in the previous offering of the lab. Several students commented that the PSpice assignments were very instructive and effective. Note also that we spent literally only a few minutes discussing the single use of MATLAB in the course. As for the technical and oral communications skills, assessment would indicate that more time discussing effective oral presentations is merited.

The third part of the survey had questions geared towards course improvement. These questions, and some of the most interesting responses, are as follows:

Additional Survey Questions:
II. Please answer these questions (add comments to the back of this sheet or attach pages if necessary)

a. What can be done to improve the lab manual?

- *Add additional circuit variations so students can make more comparisons*
- *Ensure parts used in manual match parts list*
- *Need better explanation, clearer goals, clearer idea of what to turn in*
- *Add a FAQ section*
- *Have the complete manual available (a bound, color version is best, but online is okay) at start of semester*
- *I liked how in the later labs there were data tables to fill in. This helped with me visualizing how different components affect the radio.*
- *A running schematic of the radio with suggested values next to each part*

b. What items or tools not formally required would you recommend students have to most effectively succeed in this lab?

- *Students should have their own handheld multimeter, cables, small plastic flat head screwdriver, tweezers, extra components. Wire kits are convenient*
- *Students need a parts box (tackle box?) to organize their parts*
- *If possible, take the analog course as a prerequisite or corequisite for this lab!*
- *Having experience with PSpice is important*
- *A variety of extra resistors, caps, etc so student can experiment*

c. What else can be done to improve the lab?

- *More detailed lectures and clearer goals*
- *Have some teamwork early on so project might go smoother*
- *A simpler circuit would be better even if it only picks up one station. Then, extra time could be used to improve the radio.*
- *Many of the labs can be combined; don't need two weeks for some of them*
- *Students would learn a lot if short research papers were assigned on various aspects of the radio*
- *Allow more time for creativity, troubleshooting and projects*

d. What advice would you give students to succeed in this lab?

- *Prepare for lab by reading the manual ahead of time; do PSpice and breadboarding ahead of time if possible*
- *Do out-of-lab research on each component*
- *Avail yourself of the special extra lab session (follows lecture) on Monday afternoons*
- *If possible, try to tune your radio outside where reception is much better*
- *Building a radio is just a more complex version of legos. It ends up being pretty fun once you learn what is going on.*

There was also this unprompted comment about our first offering of the AM Radio lab:

- *I think the alpha group version of the lab worked out well. Although many people did not have a 100% working radio, I felt I learned a lot about the construction and operation of the AM radio.*

Revised Radio Lab

Based on the results of the first offering of the lab and student feedback, the course was revised for spring 2009. Table 4 shows the new timeline. The first part of the course, through week 7, consists of studying and assembling the different components that make up a single-station AM radio as shown in Figure 6. The goal is to get a working radio with fairly simple functional blocks. One change, for instance, is that the audio amplifier consists of a common-emitter amplifier followed by a common-collector (follower) amplifier. This follows well the common emitter amplifier coverage from week 2, avoiding the more complicated push-pull amplifier. Another change from the first lab is the use of a common-source amplifier (using a field effect transistor, or FET) as a high-impedance first stage seen by the antenna. This is followed by an FET follower circuit and then a common-emitter amplifier; these three amplifiers make up the "RF Amp". The use of FETs was avoided in the original version of the lab to reduce complexity. But the new RF amplifier delivers much better performance and provides an opportunity to compare the performance and merits of both BJT and FET amplifiers.

Table 4: Timeline for revised offering of the AM radio lab

week	Lab
1	Test & measurement
2	Common emitter amplifier
3	Simple audio amplifier
4	AM detector
5	RF amplifier: the CS amp
6	Antenna
7	Demonstrate working radio
8	Mixer and band pass filter
9	Oscillator
10-11	Demonstrate working heterodyne radio
11-13	Work on special projects
14	Project Presentations

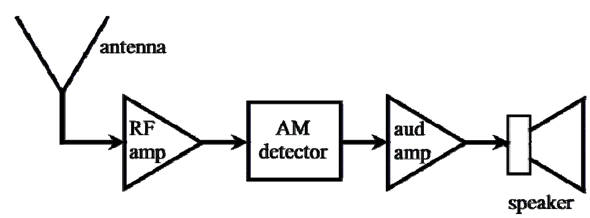

Figure 6: Single station AM radio

As in the first offering of the course, students begin working in teams of two or three students when designing and building the antenna. This is good practice for them as the team must then work together for the heterodyne version of the radio, and for the design project to enhance their radio.

After successful completion of this simple version of the radio, students proceed in weeks 8-11 with a more advanced heterodyne version which would allow tuning for different stations (a version of Figure 1). The subject matter is more advanced, dealing with signal spectra. Students continue to advance in their PSpice skills, viewing an AC sweep and viewing spectra via a Fast Fourier Transform feature. The circuits for the bandpass filter and the mixer are relatively straightforward, while the oscillator is more complicated, requiring feedback for oscillation.

In the final part of this course, students and their instructor will agree on a project topic that involves modifying the radio to enhance its performance. One possibility is to improve the gain and power efficiency of the audio amplifier. The push-pull amplifier could be investigated, as well as an audio amplifier constructed using the LM386 integrated circuit. Other possibilities include adding feedback to stabilize the output for different levels of station strength, adding a circuit for adjusting bass/treble of the output, adding a signal strength meter, or adding a received frequency display.

Two other significant changes have been made to the course. First, the PSpice simulations for a portion of the radio are now a pre-lab assignment that students must do before they can begin working on the breadboard. Second, the lab manual has been revised to include clearly labeled areas where students must fill in their answers, room to jot down answers to questions, and many more plots and tables to fill in.

Conclusion

A new junior level core laboratory has been developed in which students build an AM radio. Each functional block of the radio is studied, simulated with PSpice, constructed on breadboard and tested. Towards the end of the semester, student teams work on design projects to enhance their radio performance. Compared to a previous version of the lab where a kit radio was assembled, students in the new lab appear to gain a more thorough understanding of radio operation. They certainly have a greater appreciation of PSpice.

Based on the performance of the radios, results of design projects, and student feedback, it is anticipated that this lab will continue to evolve and improve.

References

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