

Hands-On Hardware and Simulation Experiences Used To Improve An Analog Communications Technology Course

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During the past three years teaching the analog communications course for technology students the author with help from other faculty and students has worked to improve the learning experience through use of simulation tools and hardware-building experiences. The course-improvement process is not complete and hopefully never will be. This paper describes work in three areas:

- Simulation – analyze and simulate transmitter and receiver functions and circuits.
- Antenna Building - design, build and test an antenna by teams of two or three students.
- Circuit Building - analyze, simulate, build, and test stages in an AM/FM receiver.

The text used for EET 456, Communications I, is Modern Electronic Communication, Jeffrey S. Beasley and Gary M. Miller, 8th Edition. Prentice Hall.

The description of the course as given in the University bulletin is,
Communications principles and systems. Practical engineering aspects involved in modulation-demodulation, receivers, transmitters and filters. Also included are radiation and antennas, guided waves, microwaves, and microwave systems.

The course outcomes are such that after completing EET 456, the student will be able to:

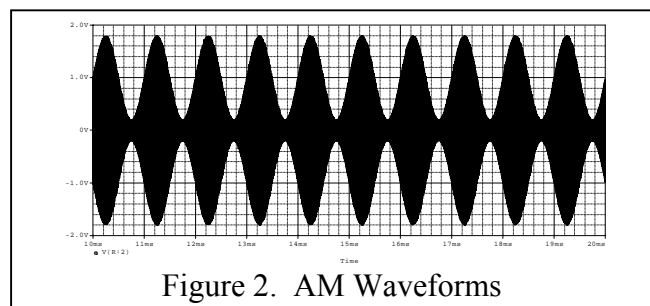
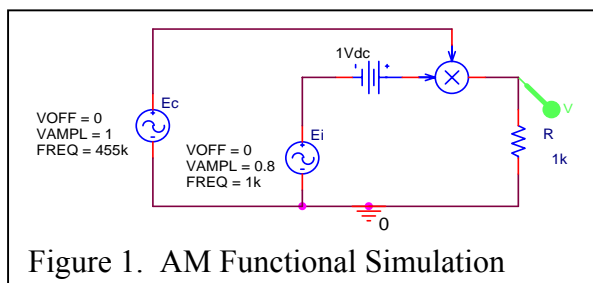
1. Relate signal voltage and power levels to decibel equivalents.
2. Calculate output signal-to-noise ratio of an amplifier given the input signal-to-noise ratio and noise figure.
3. Design, fabricate and measure the performance of an antenna.
4. Understand the signal spectrum of a square wave.
5. Describe the typical frequencies of operation of communication equipments and the bandwidth requirements of applications such as telephone, TV, broadcast radio, internet, etc.
6. Draw signal waveforms and frequency spectra in the stages of circuit stages in AM transmitters and receivers.
7. Describe frequency spectra in circuit stages of a superhetrodyne receiver.
8. Describe frequency spectra in circuit stages of FM transmitters and receivers.
9. Estimate the sizes of antennas used for HF, VHF, UHF and microwave.
10. Use a simulation tool to observe antenna radiation pattern vs. changes in antenna design.

11. Measure microwave antenna performance in an anechoic chamber.
12. Calculate the sensitivity of a receiver given the NF, bandwidth and desired Signal-to-Noise Ratio.
13. Calculate the dynamic range of a receiver given the 3rd order intercept is power level and the receiver sensitivity.
14. Find the 1-dB compression point of a receiver given the relationship between output signal level and input signal level.
15. Determine the image frequency given the carrier frequency input to a mixer in a superheterodyne receiver and the frequency of the local oscillator.
16. Determine the selectivity of an AM receiver given the tuned-circuit bandwidth and input frequency.
17. Determine the bandwidth required to transmit an FM signal by using the Bessel function table.
18. Use the Bessel function table to determine the power in the sidebands.
19. Determine the deviation constant of an FM transmitter given the characteristics of the intelligence signal and carrier.
20. Determine the power levels of carrier and sideband outputs of AM and FM transmitters.
21. Use available circuit simulation software to simulate amplitude modulation and demodulation behavior.

Simulation Experiences

Students simulated the basic equations, functions and circuits used in AM and FM modulation and detection. These include the modulator, amplifier, bandpass-filter, mixer, and detector stages. With simulation tools they explored multiplication of sine waves, Fourier series, FFT, signal spectrum, and phase-locked loop. The simulation tool used was a free version of Orcad called Orcad CIS Lite¹. Some examples of student assignments are described below.

Students simulated the basic amplitude modulation equation, $E = (E_c + E_i \sin \omega_i t) (\sin \omega_c t)$, as shown in Figure 1. They varied the amplitude and frequency of the signal and carrier and observed changes in the voltage trace and spectrum (Figure 2).



Students simulated a simplified multiplier circuit as shown in Figure 3 and observed the effects of components signal waveforms (Figure 4) and frequency spectra (Figure 5).

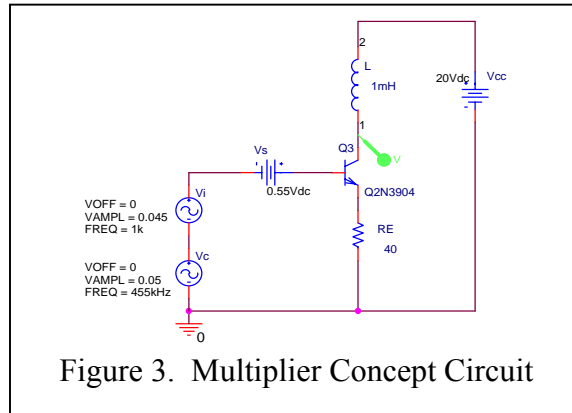


Figure 3. Multiplier Concept Circuit

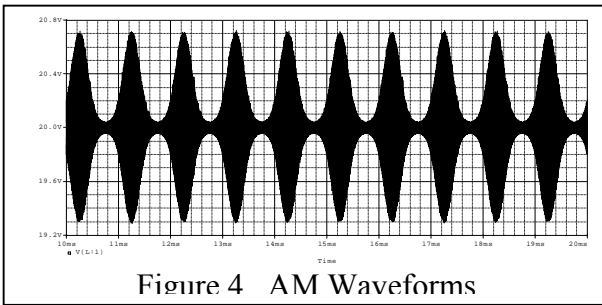


Figure 4. AM Waveforms

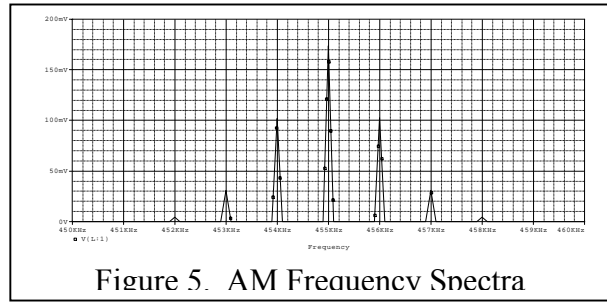


Figure 5. AM Frequency Spectra

Students simulated bandpass filter (Figure 6) and simplified mixer circuits (Figure 7).

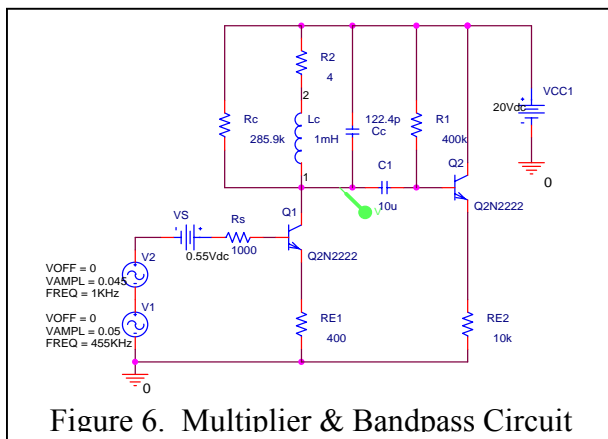


Figure 6. Multiplier & Bandpass Circuit

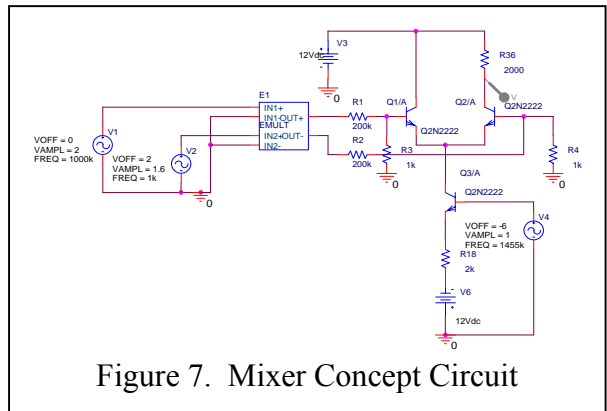
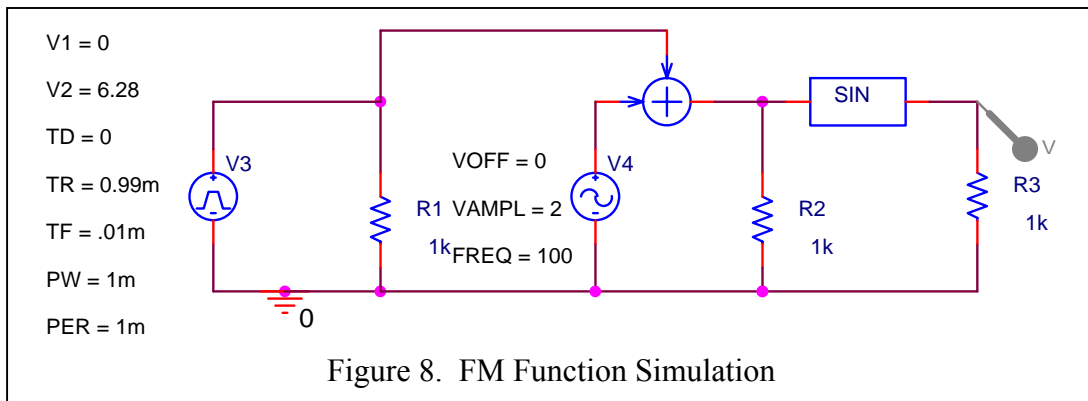
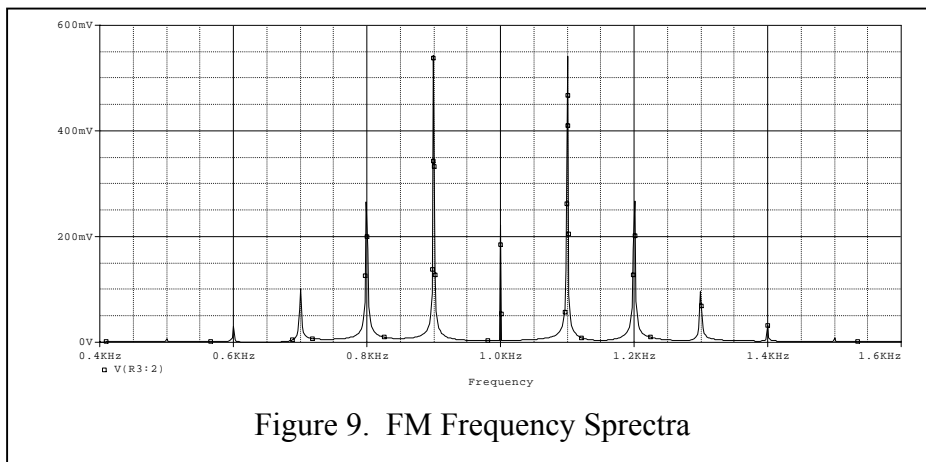


Figure 7. Mixer Concept Circuit

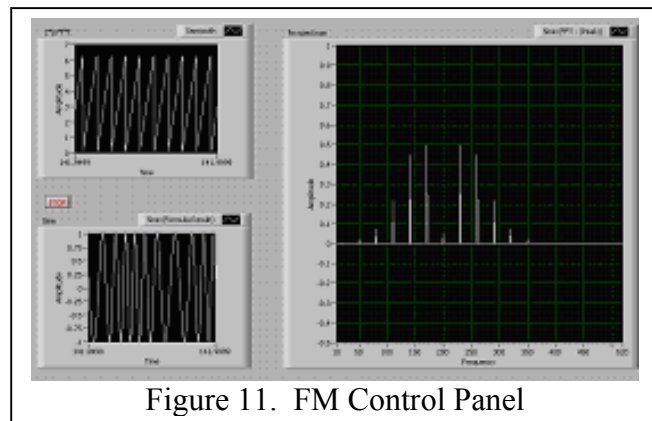
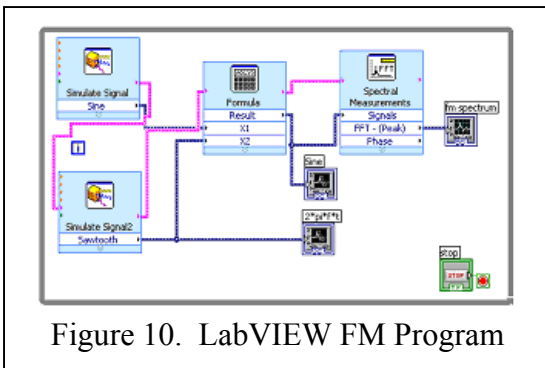
Students used the functional circuit in Figure 8 to simulate the frequency modulation (FM) equation, $e = A\sin(\omega_c t + m_f \sin \omega_i t)$. In this model a sawtooth waveform is produced by the pulse function.



The frequency spectra produced by the simulated circuit is shown in Figure 9.



Students used LabVIEW² as an alternative means of simulating FM.



Antenna Hardware-Building

In the past three spring semesters teams of two-to-three students have designed, built and tested antennas. The first year they designed 432MHz Yagi³⁻⁵ antennas with various numbers of elements. The second year the teams aimed at 144MHz. This spring the students built Quagi⁶⁻⁷ antennas having six elements and one team built a Quad antenna, all designed to be resonant at 444MHz.



Figure 12. EET 456 Class, Spring 05



Figure 13. EET 456 Class, Spring 06

The antenna building laboratories were successful in several ways. The students enjoyed building the antennas and looked forward to testing them in late spring. This contributed to good morale and favorable attitude towards the other communications subjects. The students gained a better understanding of concepts such impedance matching,^{8,9} radiation pattern, gain, wavelength, resonant frequency, etc. through the hands-on experience. They had fun testing and comparing antenna performance at the end of the course. They overcame unforeseen difficulties along the way and gained confidence in working with antennas.



Figure 14. EET 456 Class, Spring 07

Students used a free software program to experiment with different designs. They explored tradeoffs in gain, front-back-ratio, and beam-width of Yagi antennas having different numbers of elements and different element spacing. A Yagi antenna consists of a long aluminum or wooden tube with several short aluminum rods, each roughly one-half wavelength long, and spaced as determined by a design simulation program. Lengthy descriptions of the construction of these types of antennas are provided by the references. The free program, EZNEC,^{10,11} which can be downloaded from the web, provides several capabilities, as indicated in Figure 15.

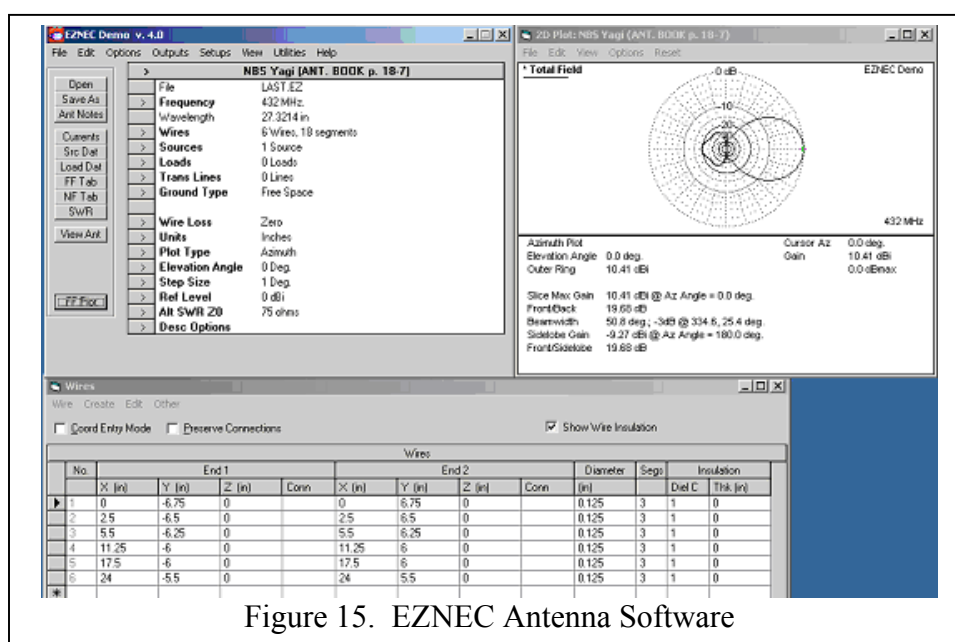


Figure 15. EZNEC Antenna Software

Frequencies in the UHF and VHF bands were given to the students as design goals. The resulting antennas were relatively small (Figure 16) as compared to an HF antenna. In the laboratory an MFJ-269 SWR analyzer (Figure 17) was used to measure the resonant frequency, SWR and bandwidth of each antenna.

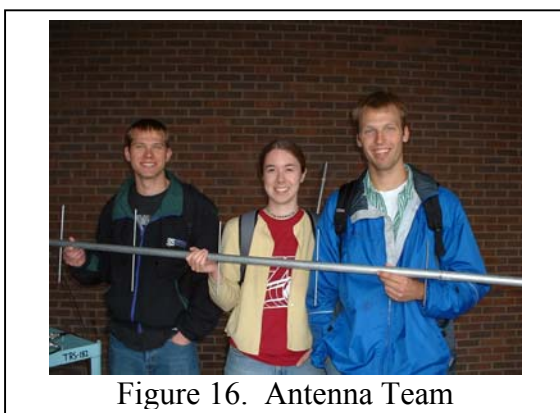


Figure 16. Antenna Team

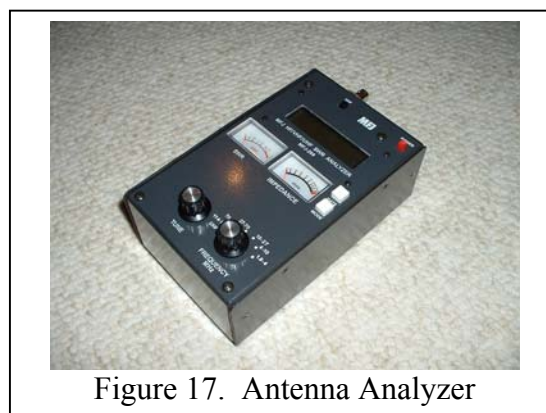
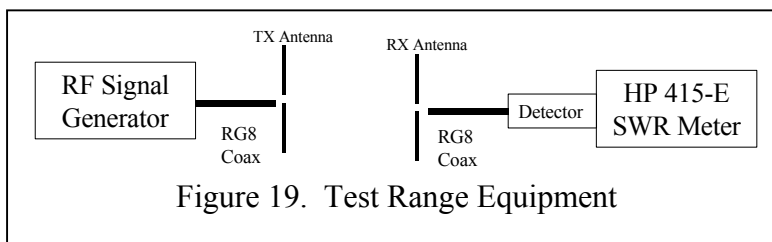
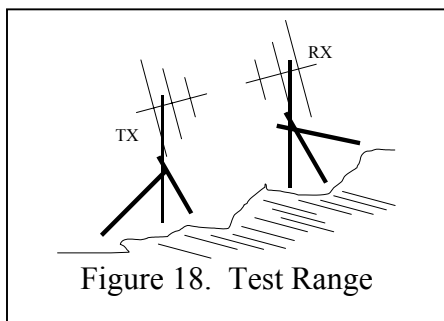


Figure 17. Antenna Analyzer

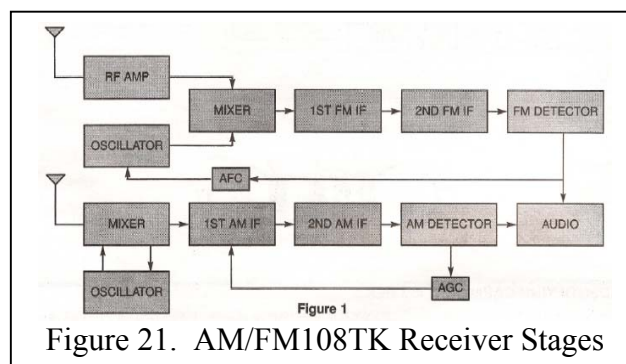
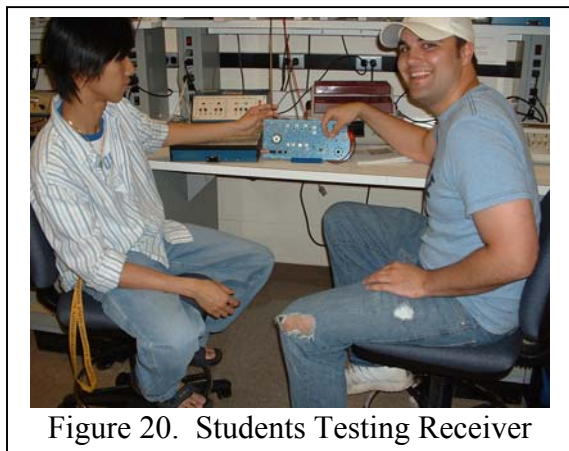
In late spring a test range (Figure 18) was set up outdoors near the communications laboratory. An RF generator was used as a source for a TX antenna. The RF frequency was set at the average of the resonant frequencies of the student antennas. A 1 kHz tone was used to modulate the RF signal. A detector and an HP 415-E SWR meter¹² were connected to the RX antenna (Figure 19). The students compared received signal strength of the antennas.



Circuit-Building

In the past a communications trainer was used in the course. Students complained about not understanding the details of circuits used in the trainer. Also, equipment issues usually were encountered. For now the trainers have been set aside.

In spring07 student teams simulated, assembled and tested AM/FM receivers. Training kits from Omnitron Electronics, AM/FM108TK, were used for the projects. Students assembled and tested stages starting with the audio output stage. They worked backwards towards the receiver front-end. They simulated some stages in the receiver, but needed more information on the transformers. When using the spectrum analyzer the students observed the same AM and FM frequency spectra in the receiver and as was shown by the simulator.



Some of the equipment used in the course is shown in Figure 22. The Tektronix arbitrary waveform generator supplied AM and FM signals to the receiver. The directional coupler was used in some initial testing of antenna resonant frequencies. The HP RF signal generator was used in the outdoor antenna tests⁸⁻¹⁰. Other laboratory equipment was used in the course including spectrum analyzers, function generators, power supplies and frequency counters.



Figure 22. Some of the Equipment Used in the Analog Communication Course

Conclusions

Student comments have been positive about the changes, particularly the antenna work. They experience some frustration when testing the AM/FM receiver work, but that is typical in component-level work. The combination of simulation and circuit building experiences gave students a feeling for the practical difficulties and at the same time a better understanding of the principles.

Some areas to improve include,

- Build simple versions of selected transmitter and receiver circuits.
- Simulate more stages of the receiver.
- Increase the number and quality of simulation homework assignments.

Students seem to be learning more in the analog communications class and enjoying the class more as indicated by test results and student feedback. A quantitative measure of improved learning is not available since I did not teach the course prior to making these changes and do not have data for those classes. There have been positive comments about the changes, particularly the antenna work, from members of the faculty who taught the course in earlier years and from the Department Chair, Professor Hudson.

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