1. **Number and title of course:** EE 117, Electromagnetic Fields and Waves

2. **Catalog description:** (4 units) Three hours of lecture and one hour of discussion per week. Formerly 117A-117B. Review of static electric and magnetic fields and applications; Maxwell's equations; transmission lines; propagation and reflection of plane waves; introduction to guided waves, microwave networks, and radiation and antennas. Minilabs on statics, transmission lines, and waves. The course begins with simple applications of static electric and magnetic fields to symmetric transmission line structures such as the coaxial cable. A gradual understanding of TEM modes is developed as wave phenomena and Maxwell's equations are introduced. Following this introduction transmission line theory and applications are considered both for pulsed and continuous wave applications. The Smith chart is introduced and the more general nature and wide applicability of bilinear transformations is emphasized. A more detailed discussion of Maxwell's equation and application are then considered; the divergence and Stoke's theorems, the Lorentz force equation and applications considered. The scalar and vector potential are introduced and the static electric and magnetic dipoles introduced as a prelude to antenna concepts. Propagation and reflection of plane waves at boundaries emphasizing the transmission line analogs is then treated. Evanescent waves and their importance in optical and other devices are discussed. Guided wave concepts, microwave networks, and radiation and antennas as well as various antenna arrays are introduced. Minilabs on statics, transmission lines, antennas, Faraday's Law, and basic optics are considered.

3. **Prerequisites:** EE40, Mathematics 53, 54, knowledge of phasor analysis (e.g., as taught in EE40), Physics 5b.

4. **Textbooks and/or other required material:**
   Over the past three years the primary texts which have been used are:
   - For additional self-help and problem practice Schawm's Outline, *Electromagnetics* [McGraw-Hill 2nd ed. (1993) was recommended]. A set of online minilab descriptions and work sheets were also available and required.

5. **Course objectives:** To provide the basic skills required to understand, develop, and design various engineering applications involving electromagnetic fields. To lay the foundations of electromagnetism and its practice in modern communications such as wireless, guided wave principles such as fiber optics and electronic electromagnetic structures including those on the sub-micron scale. To provide basic laboratory exposure to electromagnetic principles and applications.

6. **Topics covered** (Course outline)
   - **Basic Electromagnetic Wave Relationships** – Introduction to wave motion, time delay, phase speed, basic forms of the wave equation, the electromagnetic spectrum; complex phasor notation; general examples of wave motion: transverse waves on a string, analogy with electromagnetic waves; fields and potentials of electromagnetism E, D, H, B, A, and phi and the constitutive relations
   - **Transmission Line Concepts and Applications** – Circuit models of transmission lines and the coaxial line; the planar transmission line, the coaxial transmission line and its relationship to Ampere’s and Gauss’ “Laws”, basic discussion of L and C; transmission and reflection coefficients, pulses and transients; the capacitively loaded line and implications for high speed digital systems; sinusoidal waves, standing wave ratio, expressions for impedance, transmission, and reflection coefficient and power flow; Smith chart relating...
complex reflection coefficient and impedance; scattering parameters and the Smith chart; impedance matching: single and double stub tuning, quarter wave tuning; overview (only) of lossy transmission lines; basic concept of resonance on transmission lines; feedback picture of transmission lines of finite length; Gaussian pulse propagation: group and energy velocity

c) **Introduction to Maxwell’s Equations** – Gradient, perpendicularity, and wave phase-fronts; Review of vector analysis and coordinate systems; surface and volume integrals, Gauss’ law, Coulomb’s law; Gauss’ law for magnetism; line integrals, currents and Ampere’s law; divergence of a vector and Gauss’ law in differential form, the divergence theorem; curl of a vector field and Ampere’s law in differential form, Stoke’s theorem; the Laplacian operator; Maxwell’s equations; displacement current, continuity and Maxwell’s equations, charges, conduction, convection, and diffusion currents; example solutions for electro- and magneto-statics, boundary conditions; discussion of magnetic and electric potentials; Faraday’s law

d) **Intermediate Aspects of Maxwell’s Equations** – Scalar and vector potentials; dynamics, Faraday’s Law; generalizations of the potentials to include retardation; boundary conditions; capacitance and inductance; power flow and stored energy; Maxwell’s equations for the sinusoidal steady state (phasors); polarization; the steady-state Poynting vector and theorem; propagation in lossy media, skin depth; forces, torque, and work

e) **Reflection and Transmission at Interfaces** – EM waves at boundaries and the transmission line analog; Snell’s “laws” and the critical angle; oblique incidence, Brewster’s angle; TEM modes and the coaxial cable; ray model of guided waves: TE and TM waves, cutoff and phase velocity. Topics selected from the following will be discussed: General formulation of waveguide fields; hollow metallic waveguides with guiding in one dimension; two dimensional rectangular guides, the TE10 mode; general properties of power transfer; dielectric guides, conical guides, and periodic structures; slab dielectric wave guides, optical fibers, loss, and dispersion; resonators

f) **Antennas, Radiation, Diffraction, and Wireless Systems** – Basic antenna parameters for single and arrays of antennas, directivity and gain, effective area; Friis formula and its relation to uncertainty; signal to noise and the Friis equation; basic radar equation as extension to Friis equation; review of potentials and the Hertzian dipole; long wire antenna; radiation resistance; arrays; far field, near field and the Fourier transform. Possible other topics to be selected from the following: Circuit approach to arrays; Yagi-Uda arrays; integrated antennas; imaging, geometrical optics, and Gaussian beams

g) **Electromagnetic Properties of Materials** (as time permits) – Linear isotropic media; anisotropic media; introduction to electro-optics

7. **Class/laboratory schedule**: Three one hour classes per week and five minilabs (approximately one hour long each) to be completed during the course.

8. **Contribution of course meeting the professional component**: This course covers basic engineering concepts. It is primarily engineering science.

9. **Relationship of course to program outcomes**: Provides the electromagnetic basis of many of the devices and systems in modern electrical engineering: Antenna principles, the basis of p-n and MOS junction theory, and more global systems such as the global positioning based upon propagation delay being examples. Students learn how to apply fundamental mathematical, engineering and science principles to these and other basic
engineering systems involving electromagnetic fields. By working in teams during the minilabs the students are involved with team efforts to accomplish common goals.

10. **Expected outcomes:**

a. Knowledge of basic wave propagation: To be able to discuss and deduce equations to describe wave propagation, to relate wave velocity and time delay, and to be able to formulate potential concepts to relate wave properties and their excitation.

b. Should be able to specify the “constitutive relationships” for fields and understand why they are required.

c. Have the ability to apply complex phasors (Fourier) to fields for sinusoidal waves.

d. To have acquired knowledge of transmission lines for pulsed and sinusoidal steady state excitation; to have an understanding of wave interference and resonance on transmission lines; to be able to quantitatively deduce capacitive and inductive responses to pulsed excitation.

e. To have acquired techniques for the measurement of basic transmission line parameters, such as the reflection coefficient, standing wave ratio, and impedance.

f. Understanding of the Smith chart, its application to matching, and experimental verification.

g. Have an ability to determine and describe static and dynamic electric and magnetic fields for technologically important structures: the coil, charge distributions, the dipole, the coaxial cable, dielectric and conducting spheres immersed in electric fields, and the depletion region of a p-n junction.

h. Knowledge of, physical interpretation, and ability to apply Maxwell’s equations to determine field waves, potential waves, energy and charge conservation conditions.

i. Experimental measurement of voltages induced by time varying magnetic flux. Flux determination.

j. A knowledge of and experimental measurement of the influence of boundaries on waves. Thus, knowledge of and the application of boundary conditions for fields, Brewster’s angle to eliminate reflections and polarize radiation, total reflection from a boundary, evanescent fields, and some knowledge of their application to modern optics.

k. Basic concept of the guiding of electromagnetic waves by constructive multiple reflections from conductors and dielectrics. Have some knowledge of cut-off, dispersion, and why nondispersive TEM waves in ideal coaxial lines and fibers are so useful.

l. Have acquired a basic knowledge of antenna concepts, including: directivity, antenna gain, effective area, radiation resistance, and be able to carry out far-field calculations.

m. To have some knowledge of antenna arrays and their usefulness to modern wireless applications.

n. An ability to use the Friis equation to carry out basic wireless power budget calculations. The role of thermal noise.

o. Some ability to use numerical techniques such as Matlab and perhaps finite elements to solve and visualize electromagnetics.

11. **Prepared by:** Professor T. K. Gustafson (1/2008)