## REVISED COURSE: COS-IMGS-619- Radiometry

### 1.0 Course Approvals

<table>
<thead>
<tr>
<th>Approval Gran</th>
<th>Approval Requested Date</th>
<th>Approval Granted Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic Unit Curriculum Committee</td>
<td>9/1/2010</td>
<td>9/15/2010</td>
</tr>
<tr>
<td>College Curriculum Committee</td>
<td>9/27/2010</td>
<td>10/14/2010</td>
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### 2.0 Course information:

<table>
<thead>
<tr>
<th>Course title:</th>
<th>Radiometry</th>
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<tbody>
<tr>
<td>Credit hours:</td>
<td>3</td>
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<tr>
<td>Prerequisite(s):</td>
<td>Graduate standing or permission of instructor</td>
</tr>
<tr>
<td>Co-requisite(s):</td>
<td></td>
</tr>
<tr>
<td>Course proposed by:</td>
<td>John Schott</td>
</tr>
<tr>
<td>Effective date:</td>
<td>September 2013</td>
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### Contact hours

<table>
<thead>
<tr>
<th>Classroom</th>
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<tbody>
<tr>
<td>Lab</td>
<td></td>
</tr>
<tr>
<td>Studio</td>
<td></td>
</tr>
<tr>
<td>Other (specify)</td>
<td></td>
</tr>
<tr>
<td>Maximum students/section</td>
<td>50</td>
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### 2.1 Course Conversion Designation (Please check which applies to this course)

<table>
<thead>
<tr>
<th>X</th>
<th>Semester Equivalent (SE) Please indicate which quarter course it is equivalent to: SIMG 719</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Semester Replacement (SR) Please indicate the quarter course(s) this course is replacing:</td>
</tr>
<tr>
<td></td>
<td>New</td>
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</table>

### 2.2 Semester(s) offered (check)

<table>
<thead>
<tr>
<th>Fall X</th>
<th>Spring</th>
<th>Summer</th>
<th>Other</th>
</tr>
</thead>
</table>

All courses must be offered at least once every 2 years. If course will be offered on a bi-annual basis, please indicate here:
2.3 Student Requirements

<table>
<thead>
<tr>
<th>Students required to take this course:</th>
<th>(by program and year, as appropriate)</th>
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<tbody>
<tr>
<td>Graduate students in Imaging Science graduate program</td>
<td></td>
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<table>
<thead>
<tr>
<th>Students who might elect to take the course:</th>
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</thead>
<tbody>
<tr>
<td>Non-matriculated students with undergraduate degrees in the Physical Science or Engineering. Graduate students in the College of Science or College of Engineering.</td>
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</table>

3.0 Goals of the course (including rationale for the course, when appropriate):

To give the students the tools needed to solve the radiometric propagation problems they will encounter in working with imaging systems and an initial experience with using them to solve a range of common radiometry problems.

4.0 Course description (as it will appear in the RIT Catalog, including pre- and co-requisites, and quarters offered). Please use the following format:

**COS-IMGS-619 Radiometry**

This course is focused on the fundamentals of radiation propagation as it relates to making quantitative measurements with imaging systems. The course includes an introduction to common radiometric terms and derivation of governing equations with an emphasis on radiation propagation in both non-intervening and turbid media. The course also includes an introduction to detector figures of merit and noise concepts. (Graduate standing or permission of instructor) **Class 3, Credit 3 (F)**

5.0 Possible resources (texts, references, computer packages, etc.)


# 6.0 Topics (outline):

## 6.1 Review of electromagnetic energy and relevant modern physics

### 6.1.1 Definition of radiometric terms

## 6.2 Sources power, intensity, coherent, polarization, stability

### 6.2.1 Blackbody, Graybody radiators
   - 6.2.1.1 Planck equation
   - 6.2.1.2 Stefan Boltzmann law
   - 6.2.1.3 Wien displacement law
   - 6.2.1.4 Simpson’s rule
      - 6.2.1.4.1 Integration over a spectral window
      - 6.2.1.4.2 Use of blackbody tables

### 6.2.2 Sun
   - 6.2.2.1 Thermionic emission
   - 6.2.2.2 Apparent blackbody temperature
   - 6.2.2.3 Fraunhofer lines

### 6.2.3 Tungsten and tungsten-halogen sources
   - 6.2.3.1 Halogen regeneration cycle

### 6.2.4 Gas discharge and fluorescent illumination
   - 6.2.4.1 Pressure broadening
   - 6.2.4.2 Doppler broadening

### 6.2.5 Lasers
   - 6.2.5.1 Coherence
   - 6.2.5.2 Beam characteristics

## 6.3 Radiometric terms and principles

### 6.3.1 Irradiance
   - 6.3.2 Cosine law for irradiance
      - 6.3.2.1 Projected area
      - 6.3.2.2 Vector concept

### 6.3.3 Inverse square law
   - 6.3.3.1 For point source of known flux
   - 6.3.3.2 Relation to irradiance

### 6.3.4 Point source, line source, broad source
   - 6.3.4.1 How irradiance varies with respect to distance
   - 6.3.4.2 How to approximate

## 6.4 Radiance, constancy of radiance during propagation

### 6.4.1 Lambertian surfaces

## 6.5 Detectors

### 6.5.1 Thermal (bolometer)
   - 6.5.1.1 Bimetallic single element
   - 6.5.1.2 Silicon bolometer array
   - 6.5.1.3 Broadband response

### 6.5.2 Photon
   - 6.5.2.1 Quantum concept
   - 6.5.2.2 External photo effect (photoemission)
   - 6.5.2.3 Hertz
   - 6.5.2.4 work function
6.5.2.5 Phototube
6.5.2.6 Photomultiplier tube (PMT)
6.5.2.7 Microchannel plate
6.5.2.8 Internal photo effect (photoconductive, photovoltaic)
6.5.2.9 Semiconductor concepts
6.5.2.10 Forward and reverse bias
6.5.2.11 Linear and two-dimensional arrays
6.5.2.12 Read out concepts
6.5.2.13 Linear-interline
6.5.2.14 Multiple tap

6.6 Photometry
6.6.1 Photopic response
6.6.2 Scotopic response
6.6.3 Tristimulus functions
6.6.4 Chromatics coordinates
6.6.5 Color temperature vs. color distribution temperature

6.7 Detector figures of merit
6.7.1 Responsivity
   6.7.1.1 Spectral shape issues
   6.7.1.2 Materials:
      6.7.1.2.1 Indium antimonide (InSb)
      6.7.1.2.2 Mercury-cadmium-telluride (HgCdTe)
      6.7.1.2.3 Silicon (Si)
   6.7.1.3 temperature
6.7.2 Noise, Noise sources
   6.7.2.1 Read noise
   6.7.2.2 Dark current
   6.7.2.3 Photon noise
   6.7.2.4 Other noise sources
6.7.3 Signal-to-noise ratio (SNR)
   6.7.3.1 Signal processing and control vs. image SNR
   6.7.3.2 Noise reduction by averaging
6.7.4 Temporal frequency response (bandwidth)
   6.7.4.1 Rise time
   6.7.4.2 Fall time
   6.7.4.3 Bandwidth
6.7.5 Noise equivalent power (NEP)
6.7.6 Detectivity, Specific detectivity
6.7.7 Quantum efficiency
   6.7.7.1 Relationship to responsivity

6.8 Measurement Examples (Macro and quantum)
6.8.1 Source, propagation, detection, output

6.9 Spectroradiometry
6.9.1 Monochromators
6.9.2 Reflection gratings
6.9.3 Interferometers
6.9.4 Use of spectroradiometers
6.9.5 Numerical integration example

6.10 Reflection and transmission from/through surfaces
6.10.1 Specular – Fresnel Reflection
6.10.2 Bidirectional reflection distribution functions (BRDF)
   6.10.2.1 Reflectance factors
   6.10.2.2 Wavelength dependency and roughness issues

6.11 Radiometry in imaging systems
6.11.1 Lens fall-off
6.11.2 G-number – throughput
6.11.3 Imaging spectrometers (systems concepts)

6.12 Sensor performance-system level calculation
6.12.1 Instrument noise
6.12.2 Background noise
6.12.3 Detector limited performance
6.12.4 Noise-equivalent irradiance (NEI)
6.12.5 Noise-equivalent change in temperature (NEΔT)
6.12.6 Noise-equivalent change in radiance (NEΔρ)
6.12.7 Noise reduction, time delay and integrate (TDI)
6.12.8 Sampling
6.12.9 Temporal bandwidth

6.13 Integrating spheres, reflection spectrometers
   6.13.1 (Radiometric instrument examples)
      6.13.1.1 Ulbrecht integrating sphere
      6.13.1.2 Total and diffuse reflection spectrometers
      6.13.1.3 Bidirectional reflectometers

6.14 Energy exchange using non-point source calculations
6.14.1 Exchange between discs
6.14.2 General irradiance calculations for an extended surface
6.14.3 Solar irradiance calculations

6.15 Turbid media consideration
6.15.1 Transmission, absorption cross section, extinction coefficient
   6.15.1.1 Optical depth
   6.15.1.2 Brouger-Lambert Law
6.15.2 Scattering
   6.15.2.1 Rayleigh scattering
   6.15.2.2 Mie scattering
   6.15.2.3 Nonselective
   6.15.2.4 Scattering phase functions
6.15.3 Radiation propagation models
   6.15.3.1 Plane parallel
   6.15.3.2 Multiple scattering
6.15.4 Imaging radiometry in turbid media (angular effects)

6.16 Propagation of radiometric concepts through an imaging system and the role of radiometry in image analysis
6.16.1 Image chain concept
6.16.2 Radiometric analysis along the image chain
6.16.3 Specific sensor/detector example

7.0 Intended course learning outcomes and associated assessment methods of those outcomes

<table>
<thead>
<tr>
<th>Course Learning Outcome</th>
<th>Homework</th>
<th>Exams</th>
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<tbody>
<tr>
<td>7.1 Solve simple propagation problems</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7.2 Solve spectral propagation problems with noise</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7.3 Solve spectral propagation problems in turbid media</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7.4 Solve extended source propagation problems including noise</td>
<td>X</td>
<td>X</td>
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8.0 Program outcomes and/or goals supported by this course

Prepares graduate students in science and engineering for careers in the field of imaging systems
## General Education Learning Outcome Supported by the Course

<table>
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<tr>
<th>Communication</th>
<th>Assessment Method</th>
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<tbody>
<tr>
<td>Express themselves effectively in common college-level written forms using standard American English</td>
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<tr>
<td>Revise and improve written and visual content</td>
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<tr>
<td>Express themselves effectively in presentations, either in spoken standard American English or sign language (American Sign Language or English-based Signing)</td>
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<tr>
<td>Comprehend information accessed through reading and discussion</td>
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**Intellectual Inquiry**

| Review, assess, and draw conclusions about hypotheses and theories             |                   |
| Analyze arguments, in relation to their premises, assumptions, contexts, and conclusions |                   |
| Construct logical and reasonable arguments that include anticipation of counterarguments |                   |
| Use relevant evidence gathered through accepted scholarly methods and properly acknowledge sources of information |                   |

**Ethical, Social and Global Awareness**

| Analyze similarities and differences in human experiences and consequent perspectives |                   |
| Examine connections among the world’s populations                               |                   |
| Identify contemporary ethical questions and relevant stakeholder positions       |                   |

**Scientific, Mathematical and Technological Literacy**

| Explain basic principles and concepts of one of the natural sciences            |                   |
| Apply methods of scientific inquiry and problem solving to contemporary issues |                   |
| Comprehend and evaluate mathematical and statistical information                |                   |
| Perform college-level mathematical operations on quantitative data             |                   |
| Describe the potential and the limitations of technology                       |                   |
| Use appropriate technology to achieve desired outcomes                         |                   |

**Creativity, Innovation and Artistic Literacy**

| Demonstrate creative/innovative approaches to course-based assignments or projects |                   |
| Interpret and evaluate artistic expression considering the cultural context in which it was created |                   |
10.0 **Other relevant information** (such as special classroom, studio, or lab needs, special scheduling, media requirements, etc.)

Smart Classroom

11.0 **Supplemental information for Optional Course Designations:** If the course is to be considered as writing intensive or as a general education or honors course, include the sections of the course syllabus that would support this designation.
Programform.doc
NYSED Documentation Form

Audience
This document is intended for all department chairs and program directors.

Summary
This document includes the information and required forms for submission of program to NYSED for semester conversion.

Change Log

<table>
<thead>
<tr>
<th>Responsible</th>
<th>Date</th>
<th>Version</th>
<th>Short description</th>
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<td>Document originator</td>
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