Co-taught courses: TCOM 607/ECE 699 005

Satellite Communications

George Mason University

Fall 2011

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1. Announcements

This is a co-taught course for Telecommunications and Electrical Engineering students. The TCOM 607/ECE 699 005 course covers the most relevant aspects of satellite communications, with emphasis on the most recent applications and developments. The intention of the course is to emphasize the design elements of satellite communications – satellite types, earth stations, and communications techniques – building on transmission engineering concepts taught in TCOM 551/ECE 463 digital communications. After beginning with a review of the background and basic concepts of satellite communications, topics covered will include: launch systems; orbital aspects, with emphasis on the geostationary orbit and methods to achieve that orbit; satellite subsystems; design of a digital satellite link with link budget examples; modulation; error control coding; multiple access; frequency assignments and propagation aspects; antennas and earth station technology, including the design of very small aperture terminals (VSATs); non-geosynchronous orbits and their applications, in particular the global positioning system (GPS), mobile satellite communication, and satellites for Internet.
Two in-class tests will be given in week 6 of the semester (October 6\textsuperscript{th}, 2011) and week 11 of the semester (November 10\textsuperscript{th}, 2011). The final exam on December 15\textsuperscript{th}, 2011, will consist of student presentations of their research papers. If the class has substantially more than 15 students registered, the last two class days (December 8\textsuperscript{th} and December 15\textsuperscript{th}) will be given over to the student presentations. The research papers will be graded for class credit.

NOTE:

The top three term presentations will be eligible to be entered into the SSPI competition that will be run in spring 2012. A cash award will be given by SSPI to the winning presentation(s). The SSPI presentations are normally held in April.

2. Expected Background

Advanced college-level mathematics is not required, but aspects of analytical geometry introduced in ECE 463/TCOM 551 will be developed further in TCOM 607/ECE 699 005. The ability to manipulate algebraic equations, as well as being fully confident with working in the decibel notation, will be required in this course. As with all more advanced TCOM courses, concepts and techniques learned in earlier classes will be reinforced with many numerical examples.

3. Expected Learning Experience

TCOM 607/ECE 699 005 will build on the concepts introduced in TCOM 551/ece 699 005 (antennas, link budgets, propagation effects, multiple access, etc.) and then expand them to cover all facets of satellite communications. TCOM 607/ECE 699 005 will provide students with a sound understanding of both the design of satellites and the choice of orbits to use for a variety of missions, in addition to conferring the ability to design a variety of digital services that would utilize satellites as a main node, or one of the nodes, in a communications network. Students will greatly benefit from the real-world applications taught in the course.

The mandatory and supplementary text book for this course provide the bulk of the information, but substantial material for the course will be provided in PowerPoint slides. Students who have registered for the class can request the first set of lectures, but these will be sent out in any case the week before the class starts. This set of lectures, the homework assignments (and their solutions), and subsequent lectures will be distributed by Email.
NOTE: All lectures and homework assignments and solutions will be distributed to the class through George Mason University’s Email system. It is therefore essential that students activate their GMU Email accounts to obtain this information. It is a simple matter to have your Email forwarded to a preferred address from the GMU address. However, please remember you will need to clean out your GMU account regularly so as not to have a storage problem and consequently rejected Emails. Also, please do not use hotmail as a forwarding account, since you will probably not be able to receive any Power Point slides due to the size of the file (1 to 4 Mbytes).

4. Required Books and Calculator

A. Mandatory Textbook

Course Text:

NOTE: While the course will tend to follow the textbook fairly closely, additional material will be provided in class on current topics. Students are also encouraged to seek out additional references (see some possible sources below).

B. Recommended Supplementary Textbook


C. Supplementary Reading Suggestions


Acknowledgments:
Much of the material used in this course is based on notes assembled over a number of years by a variety of professors who have taught Satellite Communications, particularly Dr. Tim Pratt, Dr. James LaPean, Dr. Leila Ribeiro, Dr. Seema Sud, as well as the present instructor (Dr. Jeremy Allnutt). All material is used with permission of the author and is not to be reproduced without permission from the author.
C. Calculator

Students should have a calculator, or a PDA (or equivalent) with a calculator option. The calculator shall have the following functions, as a minimum:

(a) LOG (This key will convert an entered number into its $\log_{10}$ value)
(b) $10^x$ (This key will convert the $\log_{10}$ value back into the original number)
(c) SIN (This key will convert an angle into the sine of that angle)
(d) COS (This key will convert an angle into the cosine of that angle)
(e) TAN (This key will convert an angle into the tangent of that angle)
(f) $\sin^{-1}$ (This key will convert the sine value of an angle back into the angle; this action is sometimes called ARCSIN rather than $\sin^{-1}$)
(g) $\cos^{-1}$ (This key will convert the cosine value of an angle back into the angle; this action is sometimes called ARCCOS rather than $\cos^{-1}$)
(h) $\tan^{-1}$ (This key will convert the tangent value of an angle back into the angle; this action is sometimes called ARCTAN rather than $\tan^{-1}$)

The calculator should also have the normal +, -, $\times$, $\div$ arithmetical actions.

A number of examples in class will require the conversion from normal numerical values into logarithms (i.e. $\log_{10}$), and vice versa, in addition to using the standard geometrical functions sine, cosine, and tangent.

NOTE: Calculators will be required in the tests and exams. For this reason, advanced calculators that store equations and other processes will not be permitted. Please make sure you have only a simple calculator for the closed book, closed notes tests and final exam. Unusual equations, or long equations, will be given to students in exams in the form of a handout sheet. The key to the exams is being able to understand the processes rather than memorization. A sheet with equations will be available in each test or exam.

5. Lecture Notes

As noted earlier, Power Point slides for the lectures will be available via Email. The slides for the first lecture will be distributed ahead of that lecture, so it is essential that students have sufficient storage capacity available in their George Mason University account.

6. Homework

1. Homework Exercises will be assigned periodically (approximately once per week for the first two-thirds of the course) and are due the following week at the beginning of the class.
2. Homework will be provided by the students in hard copy to the instructor at the mid-class break of the appropriate lecture. All homework will be graded. In most
questions, what will carry the greatest number of marks will be the process in which the question has been answered, not the answer itself. Please give all intermediate steps in a question so that partial credit may be given, even though you may not have reached the correct solution. And *PLEASE* put your name and ID number on each sheet of paper and staple the sheets together.

3. Homework will not normally be accepted by Email unless prior permission has been given, e.g. a student is on travel.

4. Late homework will only be accepted
   a. With prior permission, and
   b. If the graded homework has not yet been handed back to the class.

5. To help students with travel commitments, one homework may be dropped from the total number of homeworks set. However, the tests draw most of their material from the homeworks set and so students are encouraged to complete all of the homeworks.

6. Solution sets for the homeworks will be available before the tests on those homeworks.

Students are encouraged to work together on homework problems, but they should only submit their own written work.

**6. Research Paper**

A research paper will be required for this class. The research paper will take the place of the final exam and it will constitute 15% of your overall grade.

The paper will be presented on the scheduled exam day (December 15\textsuperscript{th}, 2011). If the registrations in the class exceed 12, then the last two class days will be used for the presentations, which should run for about 12 minutes each. All students are required to attend the presentations of the other students. The grade will be assessed on both the content of your presentation and the effectiveness of your presentation. You will not be required to submit a written report, but a soft and hard copy of your presentation shall be handed in at the time of, or before, your presentation.

For the research paper, students may choose a topic in the broad area of satellite communications, in subjects related to those covered by the course, constrained by the following directions.

You should investigate a current issue in satellite communications, review existing literature on the subject and present a point of view on how the issue will evolve in the next few years. Suggested topics include, but are not limited to, the following:

(a) Phased array antennas for mobile earth stations. Or smart antennas. Questions you want to discuss on this topic are: How the technology works? How much improvement should it provide to the network when compared to omni-directional antennas? Main types of applications. Capacity and coverage issues.
(b) The future of Satellite Direct-to-Home TV services.
Some of the topics you may want to discuss include: Services offering evolution, such as Personal TV Services (TiVo, ReplayTV, etc.), Enhanced TV Services (Wink, Liberate, etc.), On-Line TV Services (AOLTv, UltimateTV, etc.). Market share and evolution compared to competing terrestrial systems. Technology evolution.

(c) The future of mobile satellite communications.
This option could have a focus more concentrated on the future, and the challenges that should be overcome for mobile systems to succeed. Discussion of system architecture and technological solutions that would make the business case more viable. Will this type of system succeed? What will make it succeed?

(d) The use of Q/V-band for satellite communications.
Some of the questions you could discuss: What are the main technical challenges of going to this high frequency band (80-100 GHz)? Is it economically viable? What are the limitations? How soon could systems be commercially operational?

(e) The future of satellite direct-to-home broadband internet services.
Some of the questions you may want to address are: What is this technology? Who are some of the current providers (e.g. Starband, DirecWay) and how are they able to compete with terrestrial access methods such as DSL, cable modem and MMDS wireless systems. Will upcoming systems succeed? Will this technology succeed? How? Why have some systems (e.g. Astrolink) failed?

(f) Launching technologies evolution.
What are the most recent technological innovations on launching vehicles? How should launching evolve in the next years? Disposable vs. reusable launch vehicles. Possibility of using space stations as a staging area for final assembly and test in space conditions.

(g) Tracking, telemetry and control evolution.
Discuss tracking and ranging technology available both for GEO and NGSO (non-geostationary) systems. Present evolutions expected in this field.

(h) Environmental impact of satellite communications.
What is the impact of satellite communication evolution in polluting the space and the earth’s surface. Focus should be given on which policies and regulatory measures should be in place in order to control and limit space pollution, and technological innovations being developed to recover spatial and terrestrial waste.

(i) Satellite vs. terrestrial based communications.
Some questions to consider: What do you think is the future of satellite communications. How does terrestrial compete with satellite? What are strengths/weaknesses of satellite vs. terrestrial; how are the strengths/weaknesses affecting the evolution of these types of systems. Which type of system will be more
successful in the future. What do satellite systems need to do to more effectively compete with their terrestrial counterparts.

(j) Routing protocols for satellite communications.
What are the different protocols in use today? Describe the technology. Advantages and disadvantages of each protocol. Which ones are most suitable for satellite systems or for certain applications. Where can improvements be made. What are the challenges.

(k) Satellite radio.
How does this service address consumer demands? Will satellite radio be as popular as its sister applications, such as satellite TV, or will it fail like Iridium and other satellite systems providing phone services? Discuss one or more of the service providers (e.g. XM Satellite Radio or Sirius) and their approach to addressing consumer needs. Can satellite radio compete with other traditional forms of radio or portable entertainment?

(l) Internet delivery to commercial airlines
How is this accomplished? What is the growth projection of these services?

(m) Optical communications
Is this technology feasible for satellite-to-UAV, satellite-to-satellite, satellite-to-ground communications? What are the capture, pointing, and tracking issues?

(n) Cluster-Systems
To avoid an asset as large and expensive as a military communications satellite, consideration is being given to operating the same communications capability via a cluster of small satellites that are linked together via optical inter-satellite links. How can this be done, and what technologies would make this approach viable?

(o) Multiple use satellites
Some organizations are hosting payloads of other users on their satellites to reduce the cost burden of a large satellite and its launch (e.g. Intelsat 22). Is this approach something that is likely to increase?

If you choose a topic from the above list, you are free to discuss issues that are not mentioned, and you do not have to discuss all the issues mentioned. These are meant only as guidelines to get you thinking about the subject.

You are highly encouraged to choose a topic that interests you the most. If you are interested in working on a topic that greatly differs from the ones listed above, you are required to submit, either in hard copy form or electronically, no later than October 6th, a ½ to 1 page proposal describing your proposed work. The proposal should clearly discuss the topic, proposed method of research, and expected outcome/results of the effort. If you choose one of the topics above, or something similar, submission of a proposal is not required.
Review of the literature is mandatory; I expect you to read and comment on at least 3 papers published in journals or conference proceedings, technical reports, or books as background work for the project. However, the project is not simply a literature review. A point-of-view is also mandatory; I expect you to clearly express your point-of-view on the subject studied, supported by your research. However, the project is also not just an editorial essay. In other words, you must express your opinion on how the issue will evolve in the near future, supported by results/advances published by reliable sources.

The Internet is a valuable source of information, and you are encouraged to use it, but it is not an acceptable substitute for journals, books, or conference papers. Also, exercise caution when utilizing Internet resources, as not all information on the Internet is accurate.

**General Guidelines on your Research Paper**

These guidelines should be followed in working on this project:

- These are individual projects, and each student must independently develop a response. However, students may seek and provide comments for each other’s approach.

- The project must contain solely original material (drawings and text) not previously published, not previously submitted to journals and/or conferences, not submitted as projects for other classes, and not done as part of your job.

- It is expected that you cite previous works properly when referenced, including websites.

**Deliverables**

The research papers shall be presented in class as a Power Point presentation, or equivalent. No written report is required, but the presentation material shall be submitted in both soft and hard copy. All presentations shall be organized as follows.

- Title slide: the title slide must include project title, course, instructor name, student name, and date.
- The presentation shall follow a logical progression, e.g.: introduction, background information, motivation, description of objectives, information discovered, any analysis conducted, results and conclusions. It shall be a stand-alone presentation.
- References. A list of references used to develop the presentation shall be given. All texts, papers, manuals, reports, or other sources used in the project must be properly acknowledged. **Use the same format for references as found in IEEE journal proceedings.**
Appendices (optional). These need not be presented but should list information there is no time to present. Note that the information presented must stand on its own. Appendices can be used to provide additional detail, e.g. source code or formula derivations, or substantiation, e.g. of numerical results that are summarized in the body of the presentation.

Grading

Grading will be based both on the content of the material presented and on the presentation itself, and it will count as 15% of the overall class grade. The best three presentations will be eligible to be submitted by the student to the SSPI competition which is run in spring semesters. The winner(s) of the SSPI competition receive cash awards.

Honor Code Pledge

Please note that you are bound by the University’s Honor Code in the preparation and presentation of your report. Please make sure that the work is all your own. If you include the work of others, please make sure you cite that work clearly. Any items used verbatim should be enclosed in quotation marks with a citation as to where the original material came from.

7. Intermediate Tests

Two Tests will be given (in class) during the semester. Test 1 will be based on lectures 1 through 5 and the homeworks for those lectures, and it will be on October 6th, 2011. Test 2 will be based on lectures 6 through 10 and the homeworks for those lectures, and it will be on November 10th, 2011. The tests will be closed book, closed notes tests of about two hours each.

8. Final Exam

The presentation material and the presentation itself will constitute the final exam, as noted earlier.

9. Course Grades:

Final Course Grades will be determined by a weighted average of the homeworks, the two tests, and the research paper in the following manner:

- Regular Homework - 15%
- Test 1 - 35%
- Test 2 - 35%
A specific percentage mark will not absolutely correspond to a course grade. Normally, a final percentage score of between 90 and 100% will be some form of A, between 80 and 90% some form of B, and between 70 and 80% some form of B- to C. Usually the median score of the class is around the A-/B+ divide, although this is not necessarily the case for a class of fewer than 20 students.

10. Course Outline and Book Sections to be Covered

Lecture 1: September 1\textsuperscript{st}, 2011
\textit{Introduction to course;}
Chapter 1 of the text book

Lecture 2: September 8\textsuperscript{th}, 2011
\textit{Orbital Mechanics and launchers:}
Chapter 2 of the text book

Lecture 3: September 15\textsuperscript{th}, 2011
\textit{Link Budgets, part 1:}
Chapter 4 of the text book

Lecture 4: September 22\textsuperscript{nd}, 2011
\textit{Link Budgets, part 2:}
Chapter 4 of the text book (contd.)

Lecture 5: September 29\textsuperscript{th}, 2011
\textit{Satellites:}
Chapter 3 of the text book

Lecture 6: October 6\textsuperscript{th}, 2011
\textbf{Test No.1}

Lecture 7: October 13\textsuperscript{th}, 2011
\textit{Error Control:}
Chapter 7 of the text book

Lecture 8: October 20\textsuperscript{th}, 2011
\textit{Propagation Effects:}
Chapter 8 of the text book

Lecture 9: October 27\textsuperscript{th}, 2011
\textit{VSAT:}
Chapter 9 of the text book
Lecture 10: November 3rd, 2011  
*Non-Geostationary Satellite Orbits*  
Chapter 10 of the text book

Lecture 11: November 10th, 2011  
*Multiple Access:*  
Chapter 6 of the text book

Lecture 12: November 17th, 2011  
**Test No.2**

*November 24th, 2011 – Thanksgiving Holiday: no class*

Lecture 13: December 1st, 2011  
*GPS Systems*  
Chapter 11 of the text book

Lecture 14: December 8th, 2011  
*DBS Systems*  
Chapter 12 of the text book  
(Or first set of presentations of research papers)

December 15th, 2011  
**Final Exam**  
Presentations of research papers