Satellite Communications - TCOM 607

George Mason University

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1. Announcements

This course covers the most relevant aspects of satellite communications, with emphasis on the most recent applications and developments. It builds on the elements taught in TCOM 551 digital communications, which is a required prerequisite. TCOM 607 begins with a review on the background and basic concepts of satellite communications, with a review of launchers and orbital aspects, emphasizing the geostationary orbit. Satellite subsystems, launching methods, and on-board processing are also discussed. The design of a digital satellite link is discussed in detail, including link budgets, modulation, error control coding, baseband signaling theory, and multiple access methods. Frequency assignments and propagation aspects that affect the satellite link design are discussed in detail. Antennas and earth station technology are presented, including the design of very small aperture terminals (VSATs), including aspects of non-geosynchronous orbits and their applications. Finally, specific applications of satellites are also explored, including the global positioning system (GPS), satellites for mobile communication, and satellites for Internet.

Two in-class tests will be given in week 6 of the semester (February 26th, 2009) and week 11 of the semester (April 9th, 2009). The final exam on May 7th, 2009, will consist of student presentations of their research papers. If the class has substantially more than 15 students registered, the last two class days (April 30th and May 7th) will be given over to the student presentations. The research papers will be graded for class credit.
2. **Expected Background**

Advanced college-level mathematics is not required, but aspects of analytical geometry introduced in TCOM 551 will be developed further in TCOM 607. 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 will build on the concepts introduced in TCOM 551 (antennas, link budgets, propagation effects, multiple access, etc.) and then expand them to cover all facets of satellite communications. TCOM 607 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 text book for this course provides 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, should it be necessary to send such information by Email.

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. 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, and Dr. Leila Ribeiro, 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 (May 7th, 2009). If the registrations in the class exceed 15, 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?

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 March 5th, 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, 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 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. In submitting the hard copy, an additional page shall be submitted attesting to the originality of the work as the student’s own (see Honor Code Pledge below). The student shall sign that the work as being his or her own work. Please do not put your Student ID or Social Security Number on the title slide.
- 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.

Honor Code Pledge

Please include the following honor pledge on a separate page when you hand in the hard copy of your presentation.

In working on this project, I followed the principles in the George Mason University Honor Code. The work contained herein is original work. I understand and abide by the guidelines provided by the instructor for this project.

NAME 
Signature

Additional instructions regarding ethical matters:
(a) This is an individual project, and it is expected that work submitted is solely the work of the named individual. Submission of someone else’s work is a violation of the Honor Code.

(b) Whenever work that is not yours is included in a report, you must clearly reference it. Plagiarism is a violation of the Honor Code. Sentences or sentence fragments copied verbatim from other sources must appear in quotation marks and be clearly referenced, although the practice of copying text verbatim is highly discouraged.

(c) Turning in a paper submitted for another class is considered a violation of the Honor Code. It is expected that work submitted be done solely for the current course and during the current semester.

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 February 26th, 2009. Test 2 will be based on lectures 6 through 10 and the homeworks for those lectures, and it will be on April 9th, 2009. 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%
- Research Paper - 15%

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: January 22nd, 2009  
*Introduction to course*;  
Chapter 1 of the text book

Lecture 2: January 29th, 2009  
*Orbital Mechanics and launchers*  
Chapter 2 of the text book

Lecture 3: February 5th, 2009  
*Satellite and their characteristics*  
Chapter 3 of the text book

Lecture 4: February 12th, 2009  
*Satellite Link design – I*  
Chapter 4 of the text book

Lecture 5: February 19th, 2009  
*Digitization:*  
Chapter 4 (contd.) of the text book

Lecture 6: February 26th, 2009  
**Test No.1**

Lecture 7: March 5th, 2009  
*Modulation and Multiplexing:*  
Chapter 5 of the text book

**March 11th, 2009 – No class due to Spring Break this week**

Lecture 8: March 19th, 2009  
*Propagation Effects:*  
Chapter 8 of the text book

Lecture 9: March 26th, 2009  
*Multiple Access*  
Chapter 6 of the text book

Lecture 10: April 2nd, 2009  
*Error Control*  
Chapter 7 of the text book

Lecture 11: April 9th, 2009
Test No.2

Lecture 12: April 16\textsuperscript{th}, 2009
\textit{VSAT Systems}
Chapter 9 of the text book

Lecture 13: April 23\textsuperscript{rd}, 2009
\textit{Non-Geostationary Satellite Systems}
Chapter 10 of the text book

Lecture 14: April 30\textsuperscript{th}, 2009
\textit{DBS Systems and GPS systems}
Chapters 11 & 12 of the text book
(Or first set of presentations of research papers)

May 7\textsuperscript{th}, 2009

\textbf{Final Exam}
Presentations of research papers