# A SATELLITE COMMUNICATIONS COURSE FOR ELECTRICAL ENGINEERING TECHNOLOGY STUDENTS

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## ABSTRACT

Satellite communication systems are playing an increasingly important role in today's society, providing a growing number of services, such as international telephony, domestic and international radio and TV, global positioning system, transatlantic aeronautical and maritime communications, weather and environmental monitoring and imaging among others. However, despite its growing importance, this subject has not been addressed in most Engineering Technology programs as needed. With this in mind, the author has developed an introductory course on Satellite Communications as an elective course within the Electrical Engineering Technology program at Penn State Wilkes-Barre, with the intention of covering this gap between skills demanded from our graduates and what is being taught in the EET curricula.

The focus of this paper is to describe this newly developed course as well as to share the students opinions and reactions to the course. As in any Engineering Technology course, the experimental component of this course is critical to the success of its graduates. The experimental part of this course combines academic experiences to help students understand the concepts explained in the classroom, linked with hands-on experiences in receiving communications from different satellite services. In particular, these experiences are centered on two types of communications that, because they are low-cost and have open transmission, (not scrambled or codified) become ideal to bring them into our classes. First, students are exposed to non-commercial television transmissions from geostationary satellites operating in the Ku band (12-14 GHz). These transmissions are normally used as a feed link to a central station. Students need to localize the satellite, point the antenna in the correct direction regarding azimuth and elevation and choose the appropriate characteristics such as frequency and polarization of the downlink. In the second experience, students receive images from satellites in a polar orbit, managed by the US National Oceanic and Atmospheric Administration, operating in the VHF band at approximately 137 MHz. In this case, students become familiar with satellite tracking tools, the prediction of the satellite appearance times, and the decoding of the signals, among others.

This paper describes the approach to this introductory course and analyzes the students opinions and their reactions as well as the feedback received by the instructor, with the intention of sharing the author's experiences with other Engineering Technology faculty who may be interested in developing similar courses.

## Introduction

Satellite communications play an important role in today's society as they become intimately linked with much of our daily activities. Services such as international telephony, international and domestic radio and TV reception, pagers, Global Positioning Systems, weather photographs and transoceanic airplane communications among others, provide us with the information and services that we use almost daily. Because of the intrinsic properties of electromagnetic radiation at the frequencies normally used by satellite services, such as traveling in a straight line, not being affected by ionospheric changes and allowing the use of wider bandwidths, we can expect an increase in the number of services provided by satellite communications in the years to come[1]. The current congestion of the lower frequency bands is another factor that is pushing the telecommunications sector towards the use of higher frequencies.

However, despite the increasingly use of microwave frequencies and satellite communication services, few Engineering Technology (ET) programs incorporate these teachings in their curricula. This is a concerning issue as we need to produce professionals from our ET schools who will be able to work with the current and future technologies with minimal additional training. We can think of several reasons to explain the absence of these subjects in our classrooms. First, because these are relatively new services and technologies not all program directors or instructors may be familiar with them, especially given the complexity of systems operating at microwave frequencies. In second place, it may not be very clear in which ET programs these topics should be taught. Most of the current Electrical Engineering Technology (EET) programs, even at the baccalaureate level, follow a very traditional, straight approach to EET without exploring telecommunication components with too much detail. On the other hand, Telecommunication Engineering Technology (TLET) programs are not as abundant as EET programs, and some of the existent ones are heavily focused towards Networking technologies. It seems that the topics of satellite communications do not have a very clearly defined area where to be taught. A third reason why few ET programs incorporate these topics may reside in the misperception by faculty that the equipment needed to produce meaningful laboratory experiences is costly, at the same time that most of satellite services are codified, scrambled or available only by subscription and not released to the general public.

Nevertheless, industry demands, and will continue demanding, Engineering Technology professionals with knowledge of these services and their associated technology. If we want to keep maintaining the high standards of ET programs and the respect that our graduates have today, we need to not only react, but also to anticipate the needs from different industries that maybe sometime ago were far away from the focus of our ET programs, but today they fit perfectly in our revised goals as Engineering Technology educators.

## Course description and goals

With the previous points in mind, the author has developed an introductory course on satellite communications trying to cover the gap between the industry needs and the student knowledge and background acquired in previous courses in the BSEET curricula in which he teaches. The main topics of this course are presented in Table 1. These topics are covered using a mixture of lectures from the instructor, experimental work, solution of problems as a group in the classroom, in addition to several presentations from the students. A clear advantage of the structure of the topics seen in Table 1 is that after the first few topics are covered, the instructor can select which ones of the remaining topics will be covered and in what order depending on the particular interests of the students and instructor, the integration of laboratory experiments and, in general, the focus for the course.

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|---|---|
| 1.- INTRODUCTION: OVERVIEW OF SATELLITE SYSTEMS | 7.- THE SPACE SUB-SYSTEM |
| 2.- BRIEF DESCRIPTION OF ORBITS | 8.- THE EARTH SUBSYSTEM |
| 3.- THE GEOSTATIONARY ORBIT | 9.- ANALOG AND DIGITAL SIGNALS |
| 4.- PROPAGATION OF RADIO WAVES | 10.- THE SPACE LINK |
| 5.- WAVE POLARIZATION | 11.- INTERFERENCE AND SOLUTIONS |
| 6.- ANTENNAS FOR SATELLITE SYSTEMS | 12.- METHODS FOR SATELLITE ACCESS |

**Table 1. Introduction to satellite communications course outline**

## Experimental section of the course

At the time of selecting and developing experiments in this course it is necessary to keep in mind that the majority of satellite communication services are not destined to the general public, they are encrypted or require special infrastructure to receive and decode them. For these reasons, the laboratory work that deals with reception of satellite signals has to be limited to services that are not proprietary or encrypted. These are weather and environmental images captured by satellite and non-commercial television signals. A third possible choice could be the use of Global Positioning Systems (GPS) that can be considered in future courses as reported by Gray and coworkers that use GPS in a similar course although with different academic goals and objectives[2]. The problem with using GPS systems in the course described in Table 1 resides in the fact the GPS receivers are normally extremely compact, as they integrate the antenna, receiver and presentation display in a handheld unit making it difficult if not impossible to study and evaluate each one of these subsystems independently. Other academic institutions have also successfully used Amateur Satellite systems as the workhorse of their educational laboratories[3]. With these considerations, the following are the specific goals for the experimental section of this course:

- To contribute to providing a basic understanding of satellite communications
- Understand the differences between polar-orbit satellites and geostationary satellites
- Understand the differences between the different types of information carried by satellites
- Acquire the ability to use software designed to predict satellite passes
- Understand the basic working principles and differences between the different types of antennas
- Understand the working principles of the several modules in the receiving station: Antenna, receiver, converter, decoder, etc
- Use the concepts of azimuth and elevation referred to the positioning of an antenna for a geostationary satellite
- Acquire images from a satellite transmitting television signals in the Ku-band
- Translate the theoretical concept of signal-to-noise ratio to the quality of a TV signal
- Research the current weather satellites available and their transmitting frequencies
- Make the necessary adjustments in the system to improve the quality of reception
- Evaluate the influence of the dimensions of the parabolic dish on the gain of the antenna, and the effects of the antenna gain on the quality of the received signal.
- Evaluate the influence of different preamplifiers on the quality of the received images.
- Understand how different countries develop cooperation agreements to share costs associated to the launching and maintenance of satellite constellations
- Evaluate the impact of satellite communications in our global society.

All of the laboratory experiences in this course have been directly developed by this author using the resources available on campus as well as the equipment purchased through a Mini-Grant from the Engineering Technology Division of ASEE that was awarded to the author of this paper. These laboratory experiences attempt to combine concepts explained in the lecture section of the course with the introduction of new topics that complement the lectures in a practical manner. The following table lists the contents of the experimental part of this course:

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| **PRACTICUM 1: Frequency management and allocation. The United States Frequency Allocation** | **PRACTICUM 5: Introduction to High-frequency Analog Spectrum Analyzer** |
| **PRACTICUM 2: Introduction to Medium-frequency Digital Spectrum Analyzer** | **PRACTICUM 6: Antenna properties and characterization** |
| **PRACTICUM 3: Digital Spectrum Analyzer Application: Characterization of terrestrial TV signals** | **PRACTICUM 7: Detection of Satellite Television signals in the Ku-band** |
| **PRACTICUM 4: Detection of Weather Satellite Images** | |

**Table 2. List of experiments developed in the Introductory Satellite Communications course**

Experiences #4 and #7 are unique in nature as they use specific equipment for satellite communications, detecting and decoding signals from the two services previously mentioned. In Practicum #4 the students set up an outdoor antenna specifically designed for the 137 MHz band used by the Polar-orbiting satellites from the National Oceanic and Atmospheric Administration (NOAA). These satellites are almost sun-synchronous which means that they will be visible in a specific location on the Earth's surface at approximately the same time every day. The NOAA satellites that were operating with weather images in the VHF band are NOAA-12, NOAA-14 and NOAA-15 although at the time of writing this paper NOAA-14 is experiencing technical problems with the onboard imaging scanner giving very low quality images. The orbital period of these satellites causes them to pass at a specific location on Earth twice a day. These passes are known as *morning pass* and *evening pass*. Part of the student work before the laboratory experience consisted in using available on-line resources from NASA to calculate the rise and set times in which these satellites are visible from Campus for several days[4]. Although NOAA also operates geostationary satellites giving their users continuous access to weather images, the polar satellites are selected in this laboratory experience to expose the students to the characteristics of polar orbits, especially taking into account that experiences with geostationary satellites are covered in Practicum #7.

In Practicum #7, the students are exposed to geostationary satellites carrying television signals in the Ku-band. These signals are normally used by television networks to obtain and distribute feeds, as well as by foreign TV stations with programming to ethnic minorities in the country. These transmissions are in both analog and digital formats. Although in these experiences the students only used an analog receiver, the use of digital receivers is under consideration for the next time this course is offered. The main problem with these types of transmissions is that a large number of transponders using satellites in the Ku-band are not in use continuously. Also in a given satellite there is a mixture of transponders employing analog and digital signals further decreasing the number of available transmissions. In this experience, the students had to calculate the true azimuth and elevation as well as these values once corrected for the local magnetic declination as well as for the offset of the dish for a list of geostationary satellites. Once the students find a television signal and see the image and audio on the TV set, they can experience how theoretical concepts that have been explained during the lectures affect the quality of the received image. These concepts include signal polarization, the relationship between signal-to-noise ratio and the image quality, how the half-power bandwidth affects the quality of the signal when the dish is slightly rotated, etc. The benefit of this activity is then the translation of theoretical and abstract concepts into a quality that they can easily perceive.

**Course assessment and student feedback**

Although student feedback is always an important tool, it becomes more important and invaluable in cases like the one described in this paper when a course is being developed and taught for first time. For assessment to be effective it needs to be done continuously instead of being a single-action normally at the end of a course[5]. With this idea in mind, the students were encouraged to note the aspects that they liked and disliked from each particular experience and how it could be improved in the future. While not all the student suggestions could be implemented, they still provide useful information in some areas. Also, at the end of selected laboratory experiences the students were asked to fill an anonymous questionnaire to measure the outcomes of that laboratory experience.

The assessment and student feedback for the overall course was developed using a dual approach. In addition to the standard course and instructor evaluation performed by the University, a specific questionnaire for this course was also developed by the instructor. Because this new questionnaire gave the students the opportunity to write their thoughts and opinions on specific areas of the course, it provided more useful information than the University-wide evaluation that is merely based on a numerical scale. The questions asked of the students by the course instructor are listed in Table 3:

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| DID THIS COURSE MEET YOUR EXPECTATIONS? WHY? | WHAT WAS THE LEVEL OF DIFFICULTY FOR THIS COURSE? TOO DIFFICULT? TOO EASY? ABOUT RIGHT? |
| WHAT WAS REDUNDANT IN THIS COURSE? WHAT WOULD YOU ELIMINATE FROM THIS COURSE? | WHAT IS MISSING FROM THIS COURSE? WHAT WOULD YOU HAVE LIKED TO STUDY? |
| WHAT WAS THE BEST PART OF THIS COURSE? AND THE WORST? | EXPLAIN HOW THIS COURSE HAS EXPOSED YOU TO CONTEMPORARY SOCIAL ISSUES. |
| IF THIS COURSE WERE OFFERED AGAIN, WOULD YOU RECOMMEND IT TO A FRIEND OF YOURS IN THE PROGRAM? | WHAT IS YOUR OPINION ABOUT THE LABORATORY WORK? TOO MUCH? TOO LITTLE? TOO DIFFICULT? TOO EASY? |

**Table 3. Questionnaire for student feedback**

The overall response from the students was very positive for this course. Six out of the 8 students taking the course responded that the course indeed met or exceeded their expectations. The students clearly valued those activities that involved hands-on experience with satellite systems, such as the detection of weather satellite images and television signals in the Ku-band at a level much higher than was anticipated by the instructor. Five of these students clearly mentioned these experimental activities to be the best part of the course. When the students were asked to name what additional activities they would have liked to have in this course, 6 out of the 8 students responded that they would have liked additional laboratory activities in order to expose them to more satellite services. This result is consistent with the interest of Engineering Technology students in having a strong hands-on component in their courses, although sometimes the same students are reticent to increasing the laboratory portion of a course given the time that they need for laboratory preparation, development and the writing of their lab reports.

The students' comments were not as unified at the time of selecting what they perceived as the worst part of the course. The graph in Figure 1 shows the areas that the students identified as the worst part of this course.

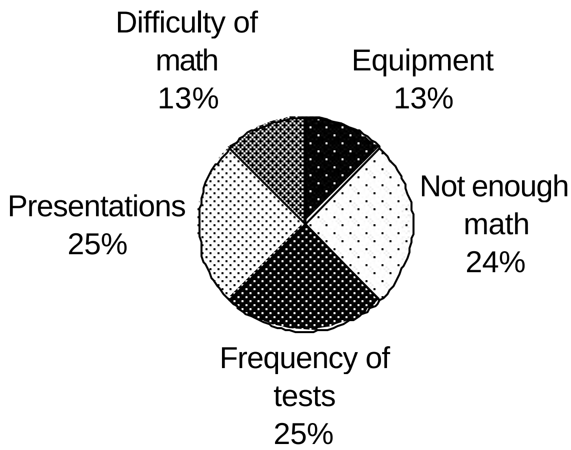


**Figure 1. Student perceptions of worst parts of course**

The analysis of the graph in Figure 1 should not surprise any educator in an Engineering or Engineering Technology discipline as it clearly shows that the students' interests and needs are different among them and in certain cases opposed. Clearly, the level of mathematics in a specific course is a topic that is far away from reaching a consensus not only between faculty members with different academic and professional backgrounds but also among the students themselves.

As it was mentioned earlier, twice during the semester, the students were required to do research on several satellite topics and present them to the rest of the class using different presentation tools and software. Table 4 lists the topics for the student presentations:

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|---|---|
| **Immarsat System** | **Intersputnik Consortium (Russian satellite system)** |
| **NOAA Search & Rescue Satellite Systems** | **APStar (Asian-Pacific satellite system)** |
| **Iridium System** | **Eutelsat (European satellite system)** |
| **Globalstar system** | **Arabsat (Arab Consortium satellite system)** |

**Table 4. Topics for student presentations in Satellite Communications**

It should not surprise any Engineering Technology educator these presentations to be identified as the least pleasant activity by the students taking this course, as we are all familiar with the students reticence to engage in oral presentations. However, we recognize the intrinsic value of these presentations, not only to comply with the current ABET accreditation criteria for ET programs, but also because of the need for our graduates to be comfortable speaking in front of an audience of their peers. An additional benefit of these kind of presentations, if selected carefully by the instructor, will be the compliance with the new ABET accreditation criteria in the area of exposing graduates from ET programs to contemporary and social issues. Through the topics that the students researched (listed in Table 4), all the students except one recognized that they were exposed to these issues by learning about the role that satellite and satellite communications play in world events, how other countries use satellite systems for communications within their own country and abroad, and how the different satellite systems interact with each other to form a global communications network. We need to keep in mind that these activities will take a more important role in the upcoming years, as the new ABET criteria for Engineering Technology programs becomes fully implemented and will have the need to create similar activities for the other courses in our programs.

## Conclusion

In the recent years, the telecommunications sector has experienced one of its fastest growing rates, probably much faster than in any earlier times, partially due to the integration of traditional telecommunication applications with higher computer power available to the general public. This revolution in the telecommunications area demands that Engineering and Engineering Technology schools be prepared to form skilled and trained professionals in this particular area. As Engineering Technology educators, we need to integrate an increasing number of high-end and specific telecommunications courses in our Electrical Engineering Technology programs. With this idea in mind, an introductory course in Satellite Communications was developed to be offered as part of our curricula in Electrical Engineering Technology. As in any other course in Engineering Technology, the experimental section of this course is critical to its success and especially to how the students benefit from this course. It is then necessary to develop meaningful laboratory activities that cover this duality: stressing the concepts developed during lecture periods and capture the attention and interest of the students. We could think that developing laboratories for a course on satellite communications can be complicated and expensive, which may stop some educators from developing similar courses for their programs. However, we have been able to identify several satellite services that provide low-cost, easy-to-develop experiences for the students in this type of course. Moreover, because the students feel that they are working with *real-world* equipment, they tend to be very interested and absorbed in these activities which results in increased learning.

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