

## INNOVATIVE TEACHING OF FOURIER SERIES USING LABVIEW

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### Abstract

Students often “glaze over” when detailed mathematical derivations are presented in class. Fourier series, the Fourier Integral and the FFT pose some significant mathematical derivations that can put any student to sleep – integrals, orthogonal functions and so on are only glamorous to the professor who relishes their derivation. However, the basic utilization of the Fourier series and FFT are very important to many applications. An understanding of their use is critical to a student’s success in several different applications such as harmonic analysis, time and frequency response, and filtering.

A lab exercise using LabVIEW is developed to demonstrate Fourier series and the FFT process along with harmonics and filtering. The students develop a graphical user interface (GUI) using LabVIEW to process simple sinusoidal signals, sum sine waves to approximate general signals (such as a square wave), take Fourier transforms, and present data in the time and frequency domain. Graphical controls (sliders or level gain) are used for both frequency and amplitude of the individual summed sine waves. The students are tasked to generate various types of waveforms and then compare the time and frequency outputs to assess the truncation of the series developed; the coefficients are then compared to the widely published Fourier series coefficients for each of the signals.

Without requiring a rigorous mathematical development, the students gain first hand appreciation of the Fourier transformation process from a very intuitive, graphical process and, at the same time, learn important features of the LabVIEW software program. The assigned project allows the students to develop their own interface with the features that are intuitive to themselves rather than using a “canned” GUI to illustrate the Fourier series process. Tutorial material describing LabVIEW overview and individual tools needed are presented in class and available as voice annotated Flash file overview. Students have used both “canned” MATLAB GUIs and standard laboratory exercises using an actual FFT analyzer with signals generated by a

function generator to observe the same phenomena. The students have overwhelmingly indicated that the individual development of the Fourier transformation via LabVIEW was a much better learning experience. The project, the results and students' observations are presented.

## **I. Problem**

Students need to apply mathematical concepts with a firm, rooted understanding of the tools that are employed. The application of Fourier Series, spectral processing, the Fast Fourier Transform and concepts of filtering need to be well understood for a wide variety of applications. The traditional approach of mathematical development of equations with homework and test problems does not appear to drive the students to learn the material for any particular reason. Implementation of laboratory exercises with lab based FFT analyzers end up causing students to become preoccupied with a "button-pushing" operation that clouds the purpose of the exercise. Somehow the students must become actively engaged in the process to become facilitators of their own learning.

## **II. Introduction**

The mission for all instructors is to educate their students in the most efficient manner possible. Teaching techniques should challenge, educate and promote innovative thinking from students. The lecture-based format of teaching which predominates in engineering education may not be the most effective manner to achieve these goals [1,2]. Constructivist learning theory asserts that knowledge is not simply transmitted from teacher to student, but is actively constructed by the mind of the learner through experiences. [3,4].

Hands-on projects and problems with practical purpose tend to help students learn best [5]. Laboratory based projects are the best vehicle for demonstrating many aspects of engineering problem solving situations. But in most cases, laboratory environments are set up as "exercises" which typically have very clear, predetermined outcomes. This is done to reinforce lecture material that is presented in related courses [6]. Students must be afforded the experience of problems that require them to formulate solutions to problems with no specific straight-line structure to the solution – they must learn how to "think outside the box" [7].

"After two weeks, people generally remember 10% of what they read, 20% of what they hear, 30% of what they see, 50% of what they hear and see, 70% of what they say, and 90% of what they say and do." [8] Clearly, the students need to drive the need for learning STEM related material.

The traditional approaches utilized in the past are described followed by the proposed approach to provide students a more meaningful framework for learning the material related to Fourier Series, Fast Fourier Transform and Filtering. LabVIEW is used as a vehicle to develop a set of virtual instruments to address the stated problem.

### **III. Description of the Previously Used Project/Lab Materials**

Using standard laboratory based FFT analyzers, a laboratory exercise has been used for many years now to address the concepts of simple spectral processing, harmonically related signals, filtering and related topics. In addition, a MATLAB GUI was introduced to enhance the students' learning and appreciation of Fourier Series and the FFT process. These two items are discussed briefly below.

#### **III.1 Spectral Processing using a Dedicated FFT Analyzer**

Several laboratory based projects have been used for over a decade. These labs introduce concepts of Fourier transforms, Fourier series, Fast Fourier Transforms, spectral processing with noise, harmonics and related topics, including frequency response measurements for mechanical and electrical systems. These labs use dedicated FFT analyzers to address these issues as part of a very well-scripted laboratory procedure. Using the FFT analyzer allows the students to concentrate on the reduction of data and visualization of the resulting processing to get a clearer understanding of this important engineering analysis. This approach circumvented the student development of computer routines and extensive theoretical development of this material, hopefully fostering a better understanding of this material.

This was thought to be an excellent exercise, and the issues pertaining to student comprehension were mainly related to the higher level of material presented and the difficulty with these complex concepts. However, the students had to be handed a fairly detailed set of FFT analyzer procedures to acquire data; this involved a long series of button-pushing operations that actually distracted the student from the comprehension of the material at hand, as was later revealed. Figure 1 shows some typical screen shots from the FFT analyzer for sine wave leakage phenomena and filter characterization and Figure 2 shows a typical FFT analyzer used with a portion of the keypad panel of the analyzer.

#### **III.2 Fourier Series Development using a MATLAB GUI**

In order to circumvent some of the problems noticed with the structured lab "button pushing exercise", a separate MATLAB GUI was developed to explore the Fourier Series for representation of common signals. This GUI was accompanied by a tutorial that presented the development of the Fourier Series to represent common signals such as square waves, triangular waves and the typical assortment of signals presented in the development of Fourier Series concepts. The tutorial presented the concepts and the GUI allowed the student to vary the frequency and amplitude of several sine waves that were summed together to form the particular time signal of interest (ie, square, triangle, etc). This enabled the student to witness first hand how the sine waves sum together to represent the time signal of interest – the frequency components were also displayed for reference. A screen shot of the GUI is shown in Figure 3.

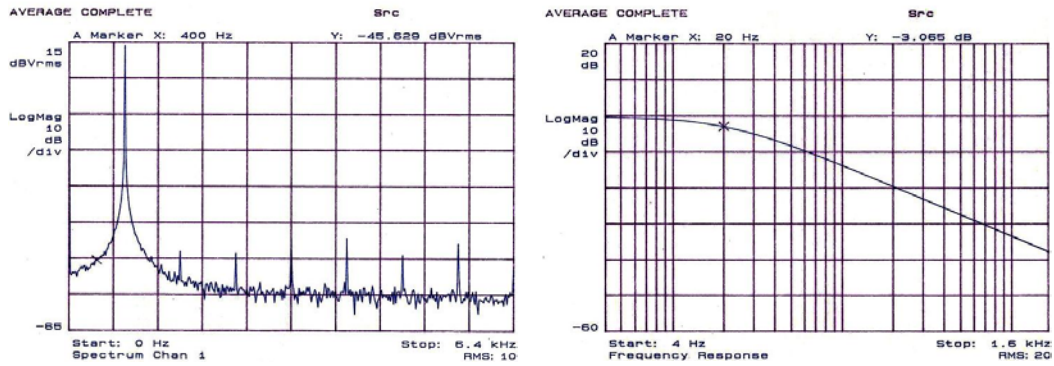


Figure 1 – Typical Spectrum – Sine Wave w/Leakage & Filter Cutoff



Figure 2 – Typical Spectrum Analyzer – Button Pushing

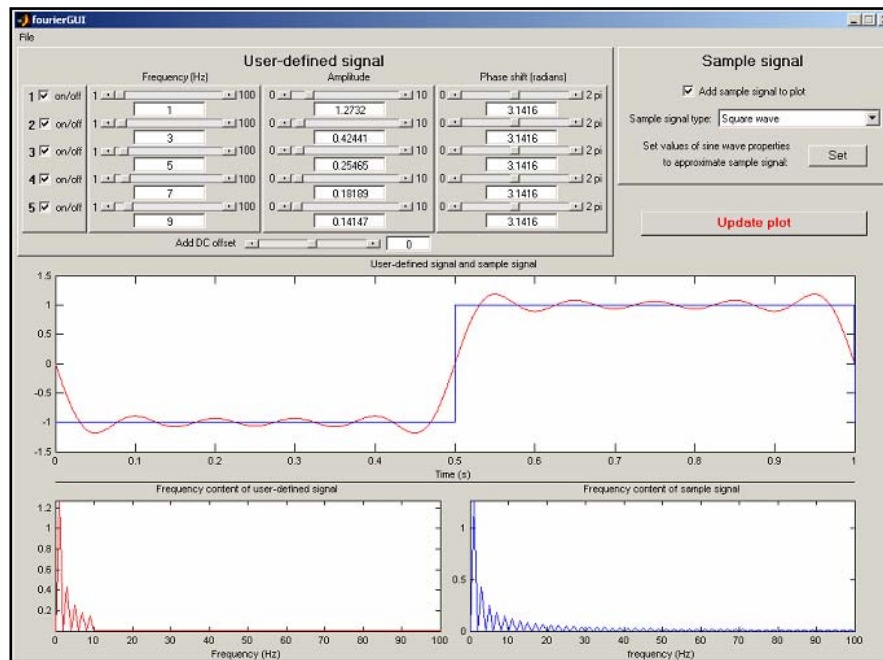


Figure 3 – Typical MATLAB GUI Interface

While the material from both of these approaches seemed reasonable from the instructor standpoint, some key features were not being adequately received and understood from the student's perspective. One aspect that became obvious was that the students (using the very well-defined set of instructions to acquire data on the FFT analyzer) were very blindly following the specific button pushing operations to acquire the specific data requested. While clear class instructions were given to let the students know that they should use the specific detailed procedure as a guide and that they should try alternate measurement scenarios for themselves, the students generally tended to follow the clear and narrow path to acquire the data mandated by the procedure. Very few students actually went beyond the limited instructions and attempted any alternate measurements to better understand the measurement being acquired. This clearly identified that the students were not willing to actually try to learn any additional material on their own. A similar situation existed with the MATLAB GUI in that the students used the interface to observe the resulting time trace on the screen but really didn't probe deeper into any of the more intricate aspects of the Fourier Series procedure. At best, the two exercises caused the students to perform a sequence of steps that really did not have any significant payback in the educational/learning process.

#### **IV. Fourier Series using LabVIEW**

In another attempt to try to bring excitement into the learning process to entice the students to accept ownership of the learning process, a LabVIEW related project was instituted to study the Fourier Series process, effects of harmonics and filtering of signals using a LabVIEW Virtual Instrument. In essence, the same project as those used previously was assigned.

The students were to take a simple sine wave and apply both amplitude and frequency controls to the signal. The signal was to be displayed in the time domain and a properly sampled digital representation of that signal was to also be presented in the frequency domain. A harmonically related sine wave was to be added to the original primary signal with its own amplitude and frequency controls. This forces the student to have a better comprehension of harmonics.

The next step was to characterize a square wave in both the time and frequency domain, again with amplitude and frequency controls. This is then followed by the overlay of the square wave with the summed set of sine waves (at least 5 recommended) in both the time and frequency domain. The culmination of this effort provides the students with a very good approximation of a square wave using a set of summed sine waves.

Of course, the realization is that the frequency and amplitude from the LabVIEW interface provide the coefficients of the Fourier Series needed to approximate a square wave. The advantage of this approach is that the students gain first hand understanding of the Fourier Series approximation, the application of the Discrete Fourier Transform, and representation of arbitrary signals in both the time and frequency domain *without ever developing a single equation of the theoretical treatment of this material*. However, subsequent presentation of the theory now takes on a very special meaning to the students since they have experiential exposure to the mathematical concepts covering this material. Additionally, as a by-product of this project, the

students get introduced to a very powerful, commonly used software package, LABVIEW. The students then proceed on to identify low pass, high pass and band pass filters to see the filtering effects on the known signals that they developed.

One extremely important aspect of this project is that the students develop their own interface. This forces them to take ownership of the material and brings self-gratification upon completion of the project. The students drive their own experience and learn the material more deeply than in previously deployed attempts at providing this material (ie, use of lab based FFT and use of canned MATLAB GUI). Since the students drive the process, they are more motivated to develop and understand the material. One “typical” student block diagram is shown in Figure 4; the front panel interface is shown in Figure 5 and 6 to illustrate a typical interface developed; another student interface is shown in Figure 7.

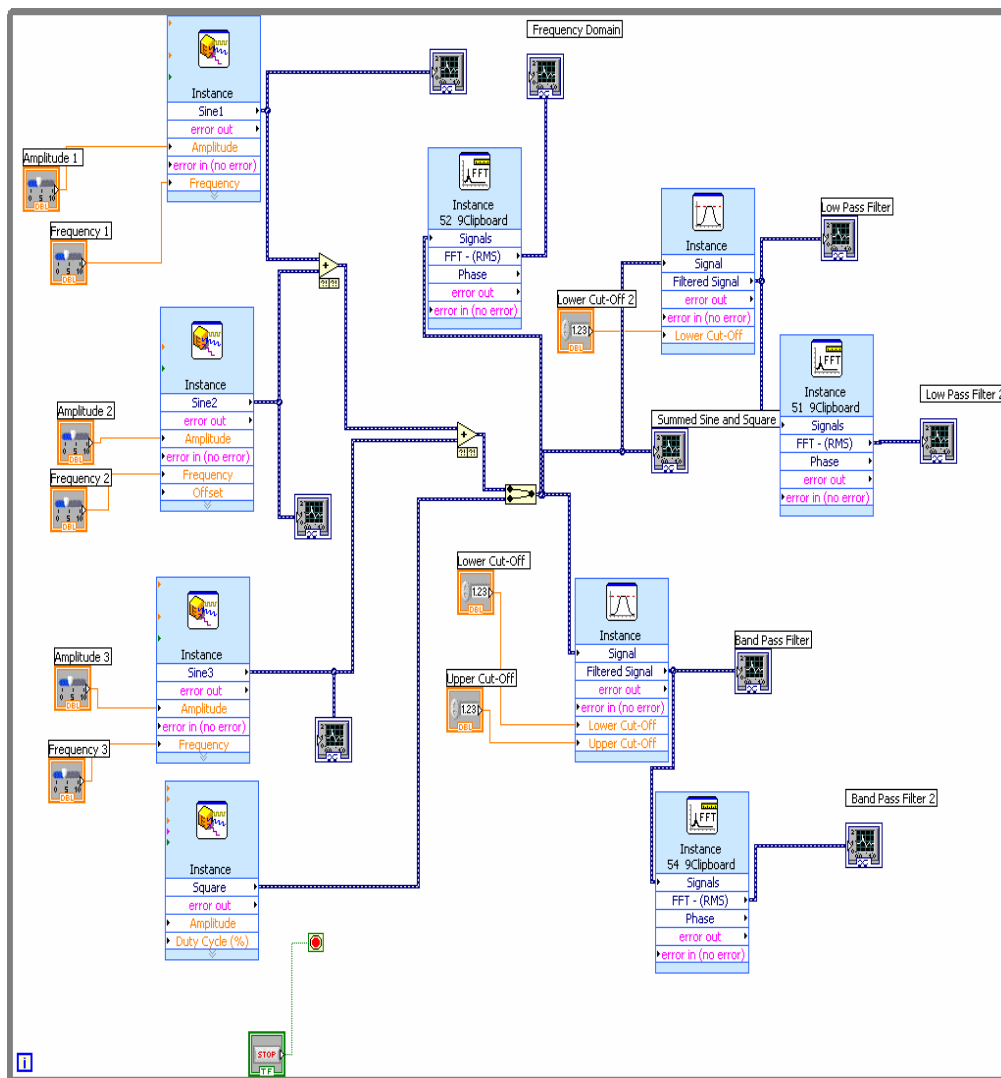


Figure 4 – Typical LabVIEW block diagram developed for the Fourier Series project.

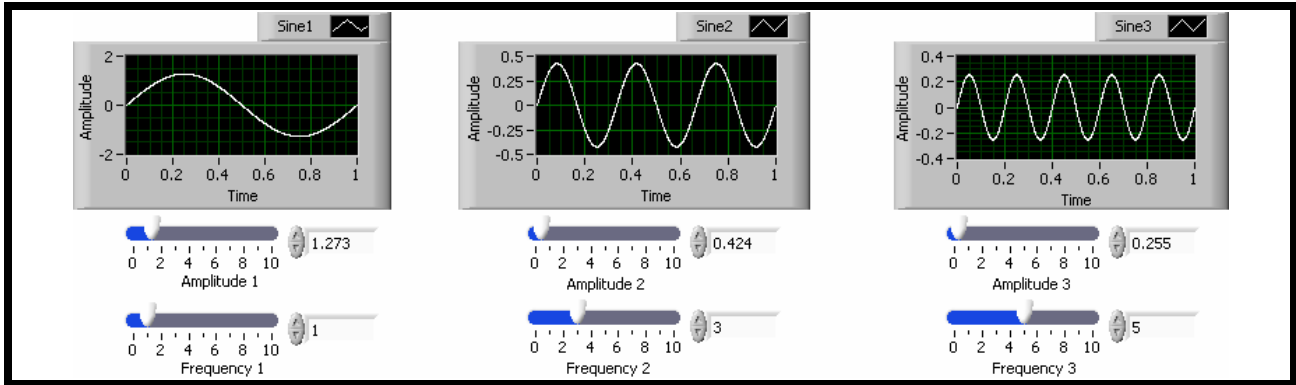


Figure 5 – Typical Front Panel for LabVIEW Sine Wave Summation

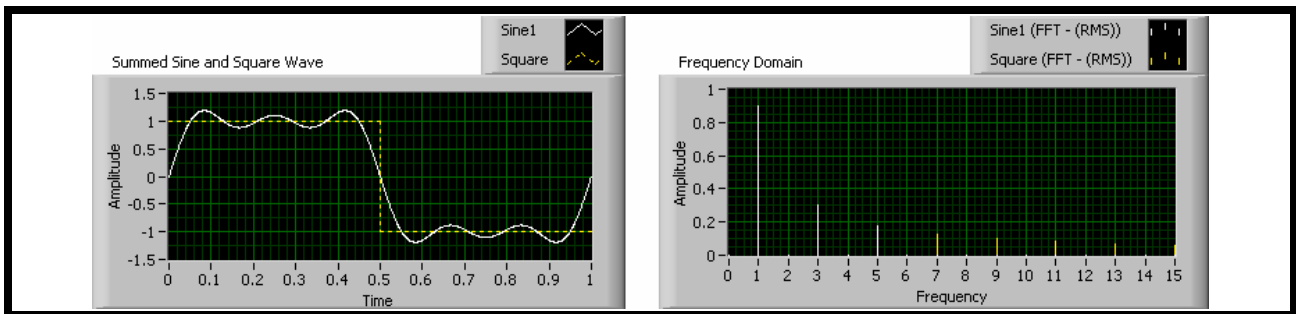


Figure 6 – Typical Front Panel for LabVIEW Summed Sine Wave & Square Wave

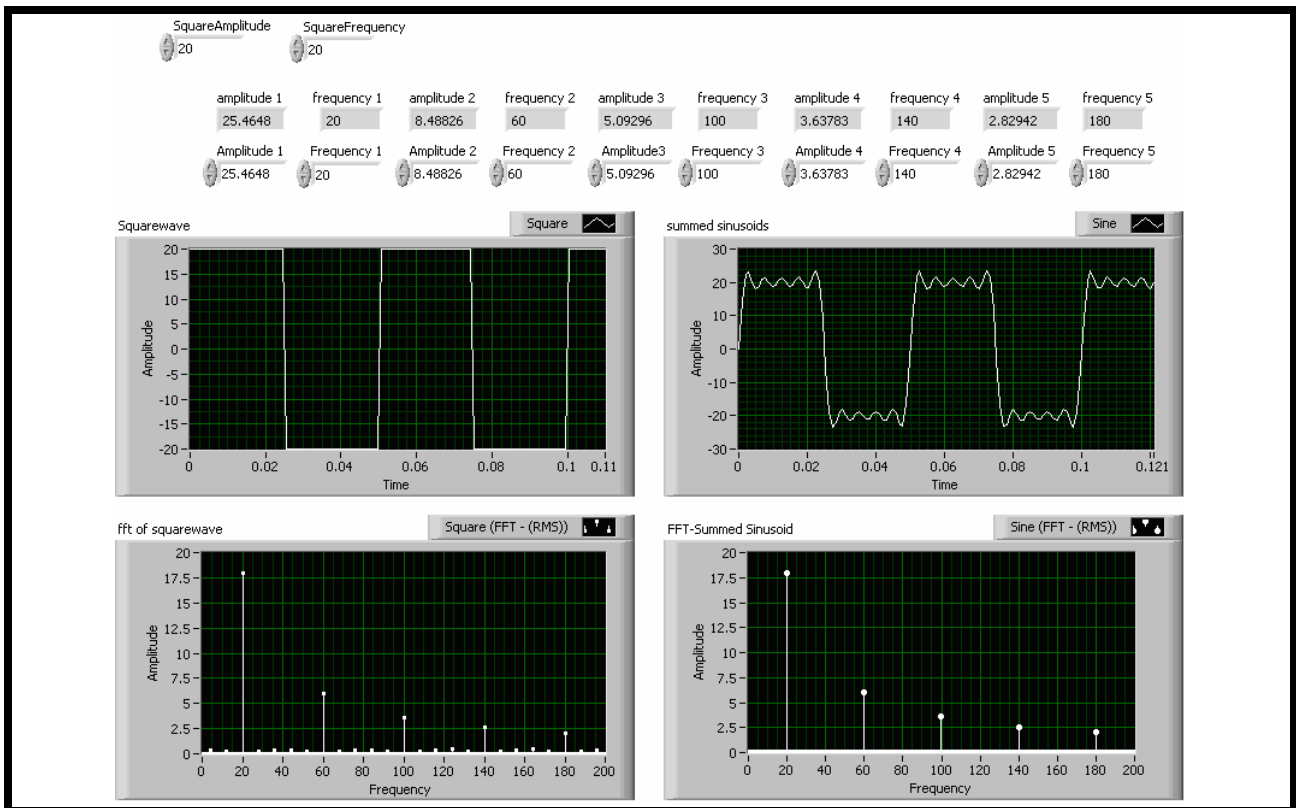


Figure 7 – Another Typical Front Panel for Execution of the LabVIEW GUI

## V Implementation of the New Project using LabVIEW

The project described was developed as an in-class assignment that lasts over a three week period, with two hours per week devoted to the project. During the first meeting period, there was a one hour introduction to LabVIEW that was specifically geared to address the project to be performed. Only the specific necessary LabVIEW features were presented rather than using any of the existing LabVIEW tutorial materials. (The LabVIEW general tutorials were more broad in nature and did not fit the needs of the specific project.) This first one hour lecture also included short overview of material from LabVIEW necessary to develop the task required. Items such as signal generation, FFT analyzer, output signal presentation, filtering, etc. were all presented to provide the novice with the rudimentary tools needed for the project. A portion of the course webpage [14] related to this specific material is shown in Figure 8.

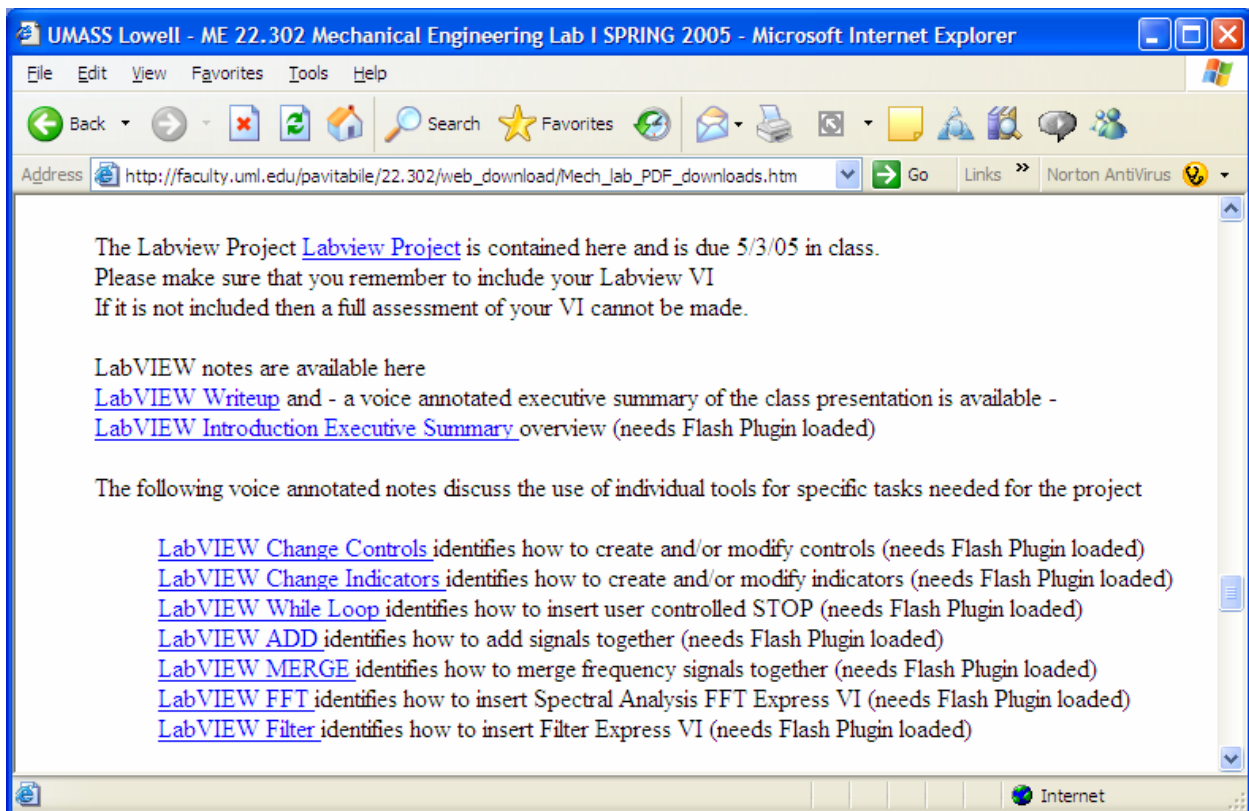


Figure 8 – Excerpt of the Course Webpage with LabVIEW Related Links to Course Material

The Power Point notes [15] generated were made available as a PDF file on the course webpage. In addition to the PDF file, a **voice-annotated streaming Flash file** [15] was generated to describe the overview of the LabVIEW lecture as well as each of the LabVIEW “tools or techniques” that are needed to complete the project; this is shown in Figure 9. This voice annotated Power Point file enables the students to review the material as needed. This provides a tremendous resource to assist the students in generating material at their own pace or for other applications. In fact, several students have used the material without attending class lectures to complete this project.



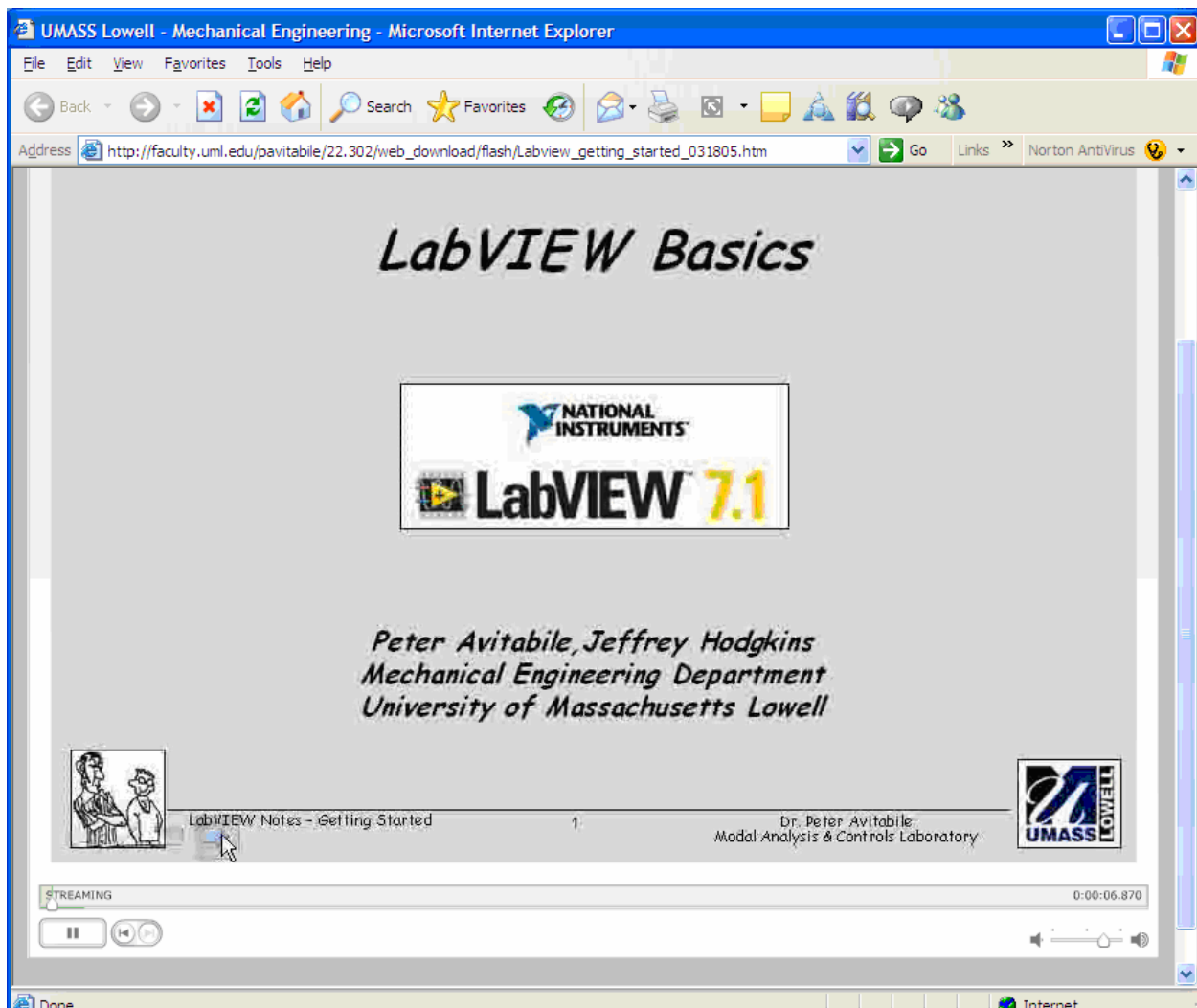


Figure 9 – Voice-Annotated Streamed Flash File of Power Point Class Notes

#### IV. Professor Observations and Evaluations

Previous implementation of this Fourier Series and Spectral Processing project using dedicated laboratory based FFT analyzers and MATLAB GUI appeared to be well-structured and provided an excellent mode to present this complex topic. While it appeared that students should be well versed after exposure to this material, many times there were deficiencies observed in later work in courses or laboratory projects. With the implementation of the student driven LabVIEW project to perform the same basic tasks, there was an observed improvement in the overall student comprehension, understanding and retention of this material. The main reason for this is directly attributed to the student driven, self motivated project that puts the responsibility of learning on the students rather than on the instructor to “implant” the knowledge into the students memory banks. The students made very positive comments about the implementation of this new project. In the last course offering, the students were exposed to the previous

approach and the updated approach presented in this paper. The students have clearly indicated that the new approach is very far superior to the previous method for deploying this material. Comments such as “now I understand this material”, “the previous lab was a boring, fast-paced unintelligible approach to the material”, “it was not obvious to me why the lab exercise using the FFT analyzer was provided” provide very real credibility to the approach described in this paper. Several candid student comments are included in Appendix A to further substantiate the statements made.

## **V Summary**

A new approach to teaching Fourier Series and FFT processing, using LabVIEW as a mechanism to deploy the material, was presented. A project involving the development of both time and frequency domain signals which are developed from sinusoidal signals to approximate standard square waves along with filtering concepts was described. Both time signals and frequency spectra were utilized as part of the project.

Earlier approaches to presenting this material utilized normal classroom lectures and laboratory exercises using stand-alone FFT analyzers. Due to the procedural and cumbersome nature for utilizing the FFT analyzer, students generally “pushed the buttons” to complete the assignments requested. While the exercises were completed, students at all levels of ability admitted that they did not fully appreciate or comprehend the material and were reluctant (ill-equipped) to use any of these techniques in subsequent projects where they were clearly necessary.

With the utilization of LabVIEW, where the students were required to “build” their own FFT analyzer to analyze both simple and complex signals, the students performed much better overall and clearly identified that the material was much more intuitively obvious with the new approach. Additionally in subsequent courses, students utilized the LabVIEW software to solve other problems without being coerced to utilize the available tools. The students have clearly identified that they enjoyed the new approach to learning this material and generally appear to have a deeper understanding of the material presented in this fashion.

## **VI Acknowledgement**

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[http://faculty.uml.edu/pavitabile/22.302/web\\_download/flash/LabVIEW\\_While\\_Loop.htm](http://faculty.uml.edu/pavitabile/22.302/web_download/flash/LabVIEW_While_Loop.htm)

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## APPENDIX A - Observations from Two Students with Candid Assessments

Student #1 (Junior level status during course) – “It was difficult to see the applicability of the Fast Fourier Transform during the FFT laboratory exercises. Besides the operation of the analyzer being overwhelmingly complicated, the signal being analyzed had many frequencies visible only in a decibel scale. Previous to the introduction of the FFT, noise not visible in the linear time domain was considered insignificant because there was no way of examining it, this thinking continued during the laboratory exercise. Leakage, windows and frequency resolution were hard to grasp and the cumbersome nature of the FFT analyzer prevented these concepts from being adequately explored in the laboratory setting.

Later in the course, I was required to make a Labview GUI which sums 5 sine waves and displays the resulting signal in both the time and frequency domain. Because the computer interface was less intimidating than the FFT analyzer and allowed for more user control of the process, this exercise allowed me to become comfortable with the FFT. A valuable part of the Labview FFT exercise was giving me a tool I could use in later classes. In the laboratory it can be cumbersome to perform an FFT on a measurement system, however if a digital acquisition system is used during an experiment, it is easy to perform an FFT on the data in Labview after the fact.”

Student #2 (Junior level status during course) – “When I first received the MATLAB GUI for using the Fourier Series, I admittedly only followed the instructions handed to me to obtain the results that were required upon submission of the assignment. When the experiment was performed with the FFT analyzer in the lab, I spent most of the time learning how to run the equipment rather than understanding what the results on the screen meant. The results from these experiments were very structured as they were designed to emphasize certain aspects of the material covered in the associated lecture material. After developing my own GUI in Labview to perform the FFT, the concepts for analyzing a signal in the frequency and time domain became more clear. I noticed other students working together and comparing GUIs in order to determine different approaches and accuracy of solutions. This not only lead to a greater understanding of the topic of Fourier Series, but also of the Labview software. I also had a greater appreciation for the MATLAB Fourier series GUI upon recent review.”