
AC 2011-458: DESIGNING ONLINE LABORATORIES FOR POWER ELECTRONICS COURSES USING J-DSP SOFTWARE

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Designing Online Laboratories for Power Electronics Courses using J-DSP Software

Java-Digital Signal Processing (J-DSP) is a web-based, platform-independent, visual programming environment that enables users to perform online signal processing calculations and simulations¹ J-DSP has been developed as a platform-independent Java applet that can reside either on a server or on a local hard-drive². J-DSP has a rich suite of signal processing functions that facilitate interactive on-line simulations of modern statistical signal and spectral analysis algorithms filter design tools, QMF banks, and state-of-the-art vocoders. The basic J-DSP environment hosts engineering algorithms for signal analysis, filtering and spectral estimation. J-DSP supports several basic as well as advanced DSP functions. Basic J-DSP functions include sampling, convolution, Fast Fourier Transform (FFT), digital filter design and arithmetic operations³⁻⁵. Advanced functions include statistical DSP algorithms, speech processing functions, multirate signal processing functions and spectral analysis functions⁶⁻⁷. In addition, it is supported by toolboxes for image processing⁸, control systems⁹, time-frequency analysis¹⁰, analog/digital communications¹¹ and earth system signal processing¹². Furthermore, several advanced functions have been developed for use in electrical and computer engineering courses¹³⁻¹⁶. In this paper, we present new functions and exercises that have been developed and deployed in power electronics courses.

1. Introduction to J-DSP Controls

J-DSP has been modified to allow control system simulations⁹, which provides a user-friendly environment for design and analysis of control systems.. All functions in J-DSPC (J-DSP Controls) appear as graphical blocks that are divided into groups according to their functionality and each block is linked to a control function. By connecting blocks together, a variety of control systems can be simulated and outputs at any point of a simulation can be examined. The controls version of the J-DSP software allows matrix manipulations and state-space analysis. Figure 1 illustrates the graphical environment of the J-DSPC editor.

Blocks can be edited through dialog windows, allowing the user to change the corresponding function's parameters to desired values and/or to view results. Dialog windows appear when the user double clicks on the center of a block. Blocks can easily be manipulated

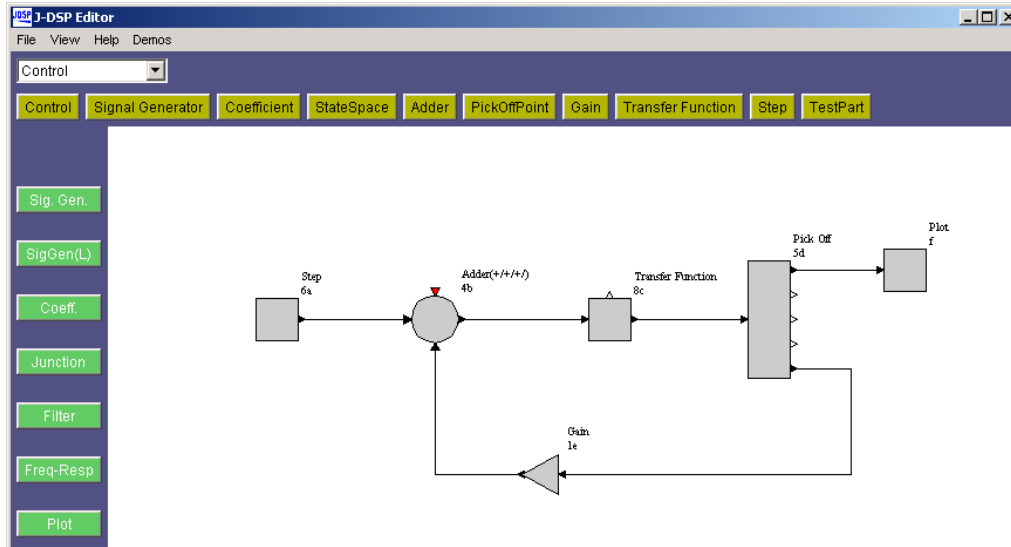


Figure 1. J-DSPC editor environment.

within the specified drawing area, using the mouse. For the original J-DSP version, all system execution is dynamic, which means that any change at any point of a system will automatically take effect in all related blocks. Any number of block dialog windows can be left open to enable viewing results at more than one point in the system. However, due to the nature of control simulations which most often require feedback, all J-DSPC control blocks have been designed to activate simulations upon command issued by the user. The simulation can only be executed if the user places the distinct Control block shown in Figure 2 on the workspace. By double-clicking on the Control block, its dialog window appears along with the *Start Simulation* button. The user needs to press the button, after building the desired control system in J-DSPC.

2. Signal Processing in Power Electronics Education

Power electronics is a critical multi-disciplinary technology that caters to a wide spectrum of applications including power supplies for all electronic equipment ranging from cell phones to mainframe computers, interface of renewable energy resources such as solar and wind, motion control automotive applications and efficient lighting. Digital control is fast becoming imperative in power electronic systems. The need for digital control is further emphasized by the challenging dynamic performance requirements in numerous applications including power management of modern microprocessors and precise motion control, for example in vector controlled ac motor drives. The interface of renewable energy resources to electric grid

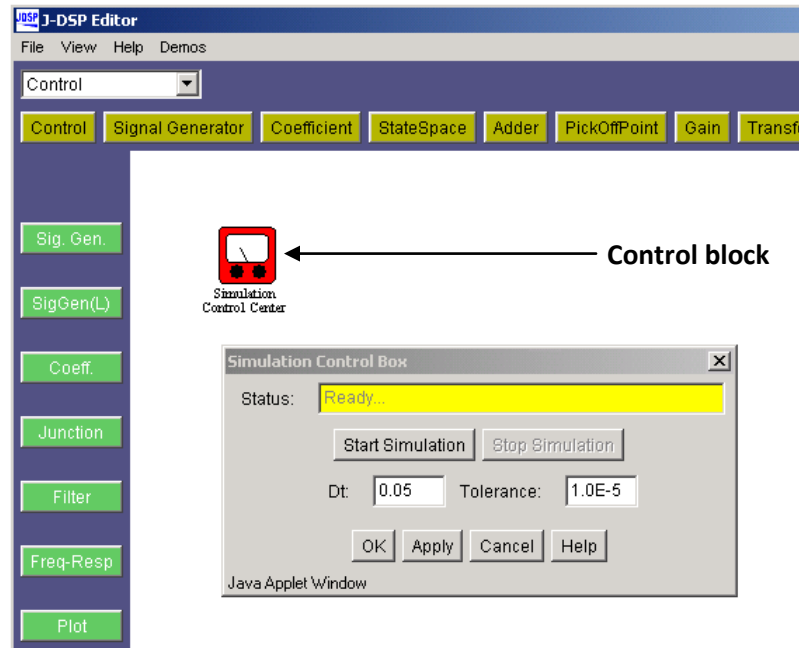


Figure 2. Control block to run simulations.

represents an enormous growth area for power electronics, and is well served by high performance digital control. For example, in a doubly fed induction generator (DFIG) used for harnessing wind energy, the objective of maximizing the energy captured from wind without compromising the grid stability and reliability requires implementation of several complex linear and non linear control laws, which can be practically realized only through digital implementation. Also, to enable high levels of penetration of intermittent and highly distributed renewable resources like solar PV, new power electronics based interconnect architectures are emerging, which require complex digital control implementation and real time communication between power converters and grid controller.

Therefore, a hands-on working knowledge of digital signal processing and digital control concepts is an essential requirement for power electronics professionals. In this paper, we propose to adapt the J-DSPC environment, in order to develop modules that can support understanding of DSP principles, and analysis and design of digital controllers suitable for demanding power electronic applications. The laboratory exercises will be incorporated in higher level undergraduate level/graduate level power electronics courses.

Functions and exercises pertinent to analysis of analog and digital systems have been developed. The students begin by constructing simple transfer function models and analyzing their step and frequency responses. The effects of feedback and cascading transfer function models are also studied. The students are also introduced to digital control and harmonic distortions associated with sine PWM systems. Exercises to demonstrate the effects of non-linear operations on signals, in terms of total harmonic distortion, and simulate the operation of a sine PWM modulator have been developed. The list of functions developed include sine PWM, total harmonic distortion, analog and discrete transfer function models, pole-zero plots and frequency domain analysis for both the analog and discrete cases.

3. Module 1 – Introduction to Simple Control Systems

In this lab module, the students are introduced to the design of simple feedback control systems and analysis of its characteristics.

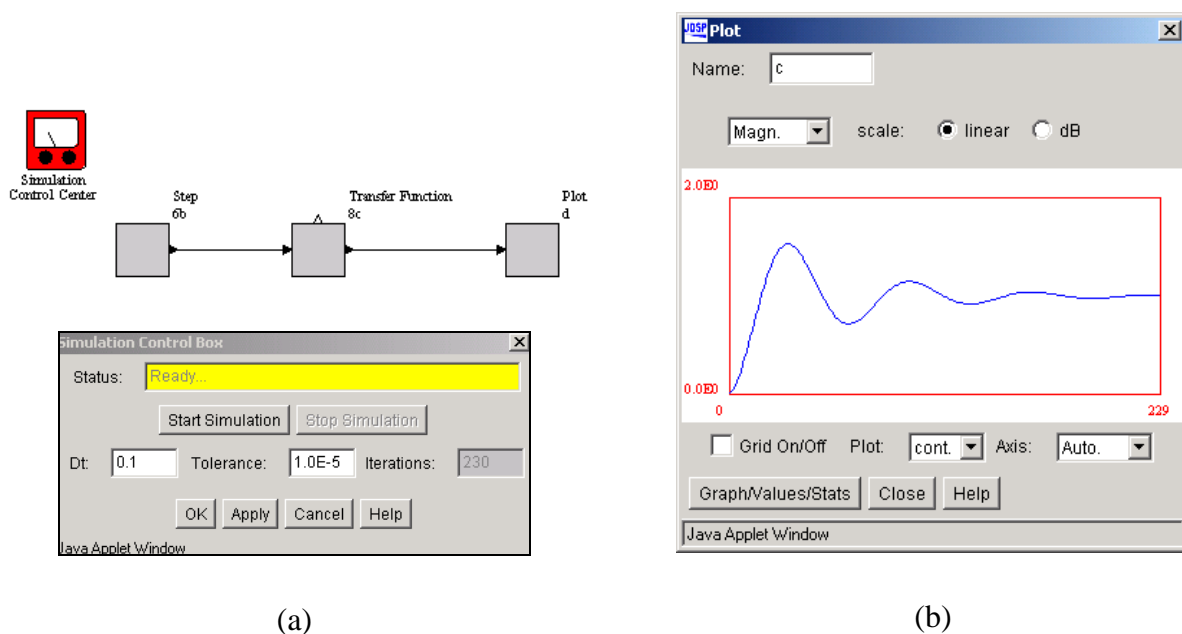


Figure 3. J-DSP simulation for plotting the step response of a transfer function model.

3.1. Step Response of Transfer Function Models

A simple system is constructed by providing the transfer function and the step response is plotted. In order to execute the block diagram, the student needs to place the *Control Block* in the workspace and set the parameter *Dt*. The student also experiments by varying the *Dt* field

and observes that the Dt field has an effect on the resolution of the output plot. Figure 3 demonstrates the block diagram and the step response obtained for the transfer function.

3.2. Cascading Transfer Functions

In this simulation, a flowgram is constructed by placing two systems in cascade. The student enters two different transfer functions into the first and second transfer function blocks respectively to obtain a workspace similar to Figure 4. Using similar procedures as in the previous exercise, *Step* and *Plot* blocks are included in the simulation.

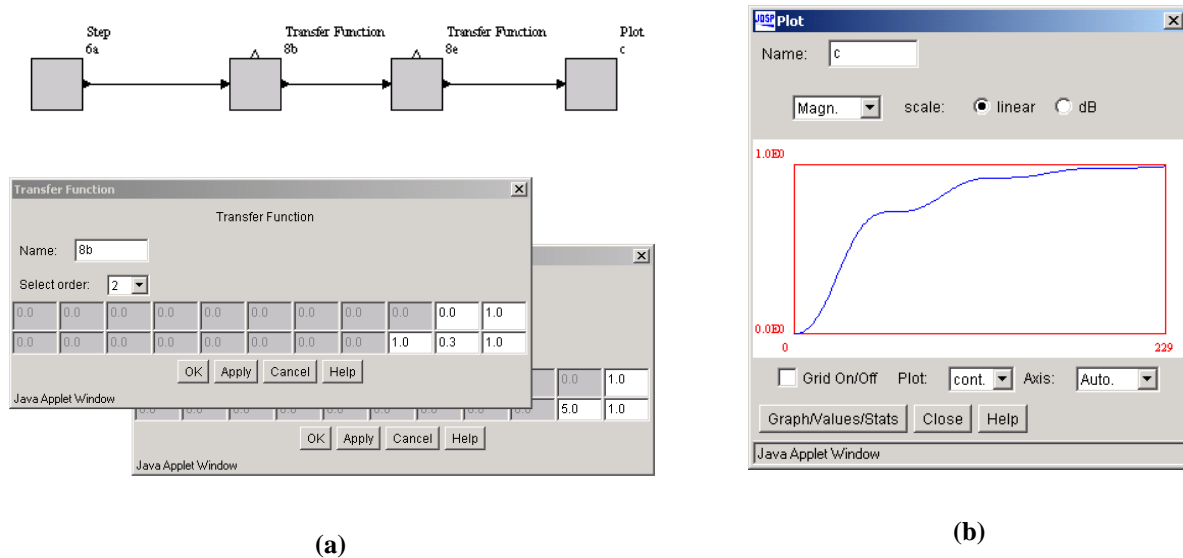


Figure 4. J-DSP simulation for cascading transfer functions.

3.3. Feedback System

The two systems used earlier remain in cascade, but a unity negative feedback is also applied. In order to realize the feedback loop, an *Adder* and a *Pick Off Point* blocks are placed in the workspace. The feedback input of the *Adder* block is set to a negative value, in order to prevent the systems from becoming unstable. This setup is illustrated in Figure 5.

4. Module 2 – Sine PWM and Digital Control

In this lab module, the students study the design of a sine PWM system and perform detailed analysis of digital control systems.

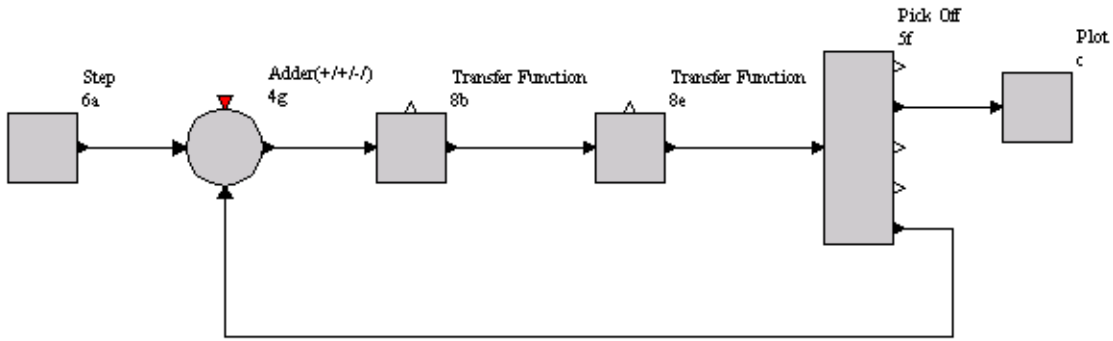


Figure 5. J-DSP simulation of a feedback system.

4.1. Total Harmonic Distortion

The total harmonic distortion (THD) of a signal is a measurement of the harmonic distortion and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Lesser THD allows the components in an amplifier or a microphone to produce a more accurate reproduction by reducing harmonics added by the electronic circuits. In this simulation, students study the harmonic distortions introduced by non-linear operations. Figure 6 demonstrates the setup for this exercise, by measuring the THD for a linear operation (Gain) and a non-linear operation (exponential).

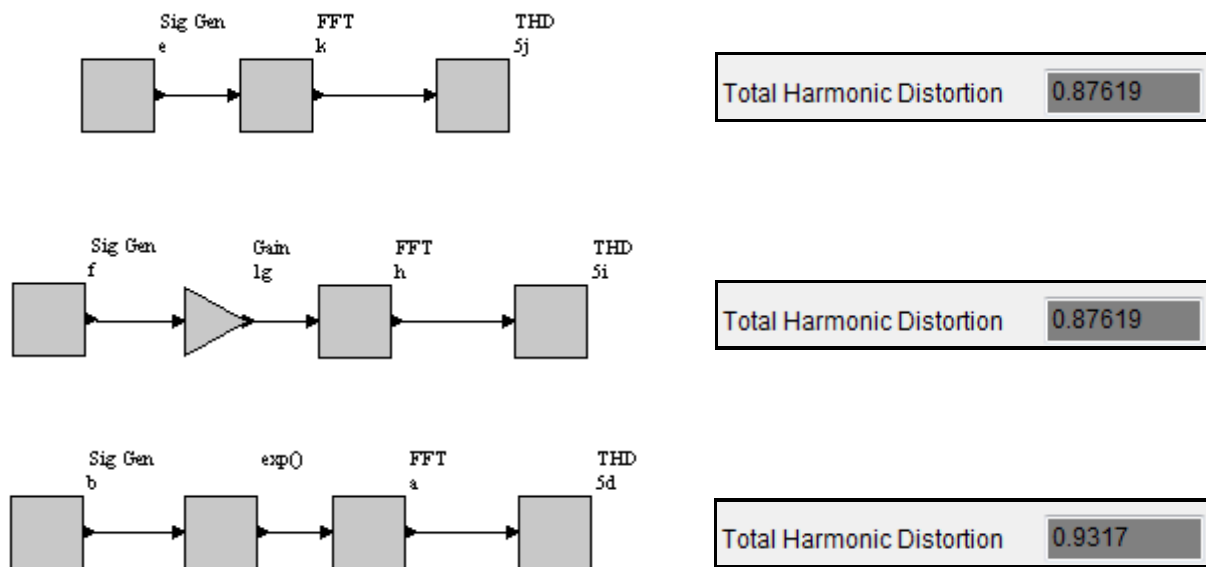


Figure 6. Effect of non-linear operations on the THD.

4.2. Design of a Sine PWM

Sinusoidal pulse width modulation is a method of pulse width modulation used in inverters. An inverter produces an AC output voltage from a DC input by using switching circuits to simulate a sine wave by producing one or more square pulses of voltage per half cycle. If the widths of the pulses are adjusted as a means of regulating the output voltage, the output is said to be pulse width modulated. The small signal model for the PWM block is illustrated in Figure 7. In this exercise, the students perform and study a sine PWM using J-DSPCs.

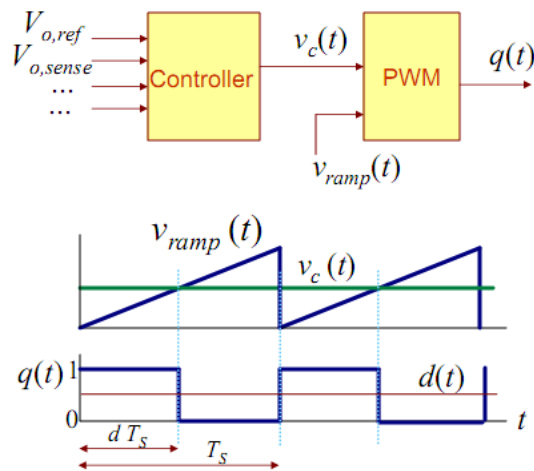


Figure 7. Illustration of the sine PWM small signal model.

There are two in-built modes of operation for the *Sine PWM* block in J-DSPC. Choosing the option *Internal* for the parameter *Threshold* will let the students set a custom threshold (v_c). However in this case the option *External* is chosen, as a triangular waveform will be used for performing PWM. Furthermore, the FFT of the modulated signal is computed in order to measure the THD. The students experiment by changing the various parameters of the simulation and report their observations.

4.3. Design of Digital Systems

In this exercise, students perform a basic analysis of digital transfer functions. In particular, they analyze the frequency domain characteristics of the designed systems. Analysis includes plotting the impulse and frequency responses, pole-zero plot and stability analysis. Furthermore, the students use the *PZ Placement* block in J-DSPC to design digital systems by

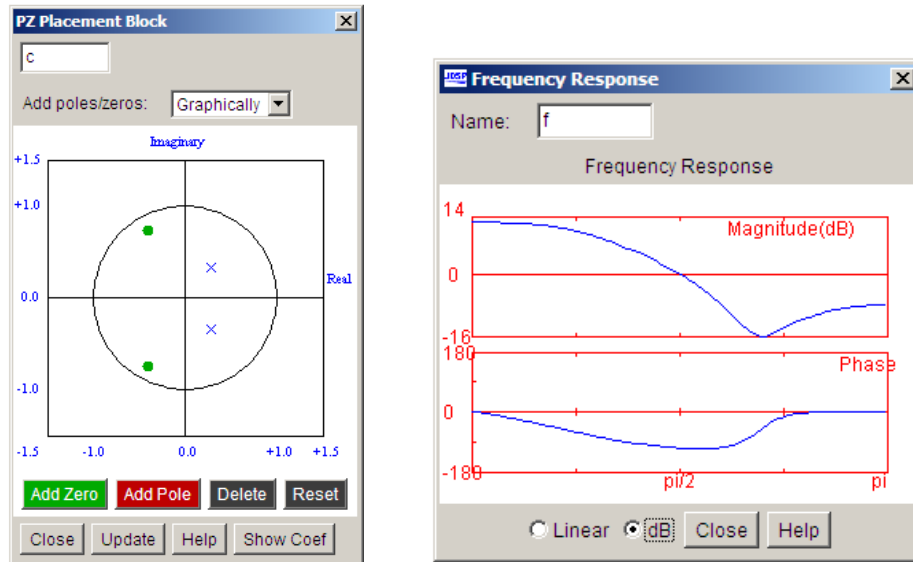


Figure 8. Effect of poles and zeros in the frequency response.

placing custom poles and zeros. Poles raise the frequency response up (create peaks) and zeros create valleys. Poles and zeros are entered in conjugate pairs to get real-valued filter coefficients. Figure 8 illustrates the effect of poles and zeros in the frequency response.

5. Assessments

The exercise modules described in the previous sections will be presented to the students as a part of an assessment task. Assessment results will be generated after the exercises are performed by students at the higher level undergraduate/graduate level in a power electronics course. The course is offered online, where the web nature of the J-DSP simulation environment will be particularly useful.

The pedagogy adopted for the integration of J-DSP laboratories in the course includes the following sequence of activities: lecture on the pertinent signal processing concepts, a prelab quiz associated with the topic, an online laboratory using J-DSP visual programming, and a postlab quiz. The prelab and postlab quizzes are part of both the pedagogy and assessment. The prelab quiz emphasizes the key concepts and provides information to the instructor and students on deficiencies and on areas that require further review. The J-DSP laboratory includes exercises that address these key concepts and enable students to improve their performance and eliminate deficiencies; the postlab quiz measures whether additional knowledge was gained and whether

deficiencies have been eliminated by attempting the J-DSP laboratory. The assessments will determine if the J-DSP labs have enhanced and reinforced student learning, particularly in topics such as analysis of analog control systems and feedback, sine PWM and digital control. In particular, the general and concept-specific assessments support the objectives associated with the J-DSP labware and the pedagogy. The general assessments are used to obtain an overall subjective opinion on the J-DSP software. The concept-specific assessments provide the laboratory evaluation and its impact on the learning. The final J-DSP software and laboratory evaluation will provide prescriptive recommendations concerning strengths, replication, and sustainability.

6. Conclusions

In this paper, we motivated the need of introducing signal processing tools for the study and analysis of analog/digital systems used in power electronics courses. In order to provide a working knowledge of some of the fundamental principles, we have developed a set of laboratory exercises using the J-DSP Controls software. The ease of implementation and accessibility makes J-DSP a suitable candidate for online laboratories for students not experienced in using programming languages. Assessment results will be generated, based on student feedback and will be presented at the conference.

5. Acknowledgements

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