Answer Booklet: Digital Signal Processing
ELEC96010 (EE3-07)

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Module 1

Self-assessment Quiz

1. Consider $x_a(t) = \cos(100\pi t)$

   (a) Determine the minimum sampling rate to avoid aliasing

   Frequency of $x_a(t)$ is 50 Hz, therefore, 100 Hz is required to avoid aliasing

   (b) Write down an expression for $x[n]$ if a sampling frequency of 200 Hz is used.

   $$x[n] = 3\cos(\omega n) = 3\cos(2\pi f n) = 3\cos\left(2\pi\frac{F}{F_s}n\right) = 3\cos\left(2\pi\frac{50}{200}n\right) = 3\cos\left(\frac{\pi}{2}n\right)$$

   (c) Write down an expression for $x[n]$ if a sampling frequency of 75 Hz is used.

   $$x[n] = 3\cos\left(2\pi\frac{F}{F_s}n\right) = 3\cos\left(2\pi\frac{50}{75}n\right) = 3\cos\left(\frac{4\pi}{3}n\right) = 3\cos\left(\frac{2\pi}{3}n\right)$$

2. If the sampling frequency is 48 kHz, what is the frequency of the discrete time signal corresponding to a sinusoid at 1.2 kHz?

   $$\omega = 2\pi\frac{F}{F_s} = 2\pi\frac{1200}{4800} = 0.05\pi$$

3. What is meant when we refer to a frequency of $\frac{\pi}{4}$?

   $$\omega = 2\pi\frac{F}{F_s} = \frac{\pi}{4} \quad \therefore \quad F = \frac{F_s}{8}, \quad \text{i.e. it means an eighth of the sampling frequency.}$$

4. Given $x[n] = (0.5)^n u[n]$, find the signals z-transform $X(z)$ and the corresponding ROC.

   $$X(z) = \sum_{n=-\infty}^{\infty} x[n]z^{-n} = \sum_{n=0}^{\infty}(0.5)^n z^{-n} = 1 + 0.5z^{-1} + 0.25z^{-2} + \cdots$$
   $$= \frac{1}{1-0.5z^{-1}}, \text{ where } |0.5z^{-1}| < 1. \quad \text{Recall } 1 + a + a^2 + \cdots = \frac{1}{1-az^{-1}} \text{ if } |a| < 1.$$
   $$\text{Thus } X(z) = \frac{1}{1-0.5z^{-1}}, \text{ where } 0.5 < |z|$$

5. For a signal $x[n]$ with z-transform $X(z)$ and ROC $r_1 < |z| < r_2$ find the z-transform of $x[-n]$ using the time-reversal property.

   $$\mathcal{Z}\{x[n]\} = X(z) = \sum_{n=-\infty}^{\infty} x[n]z^{-n} \quad \text{ROC:} \quad r_1 < |z| < r_2$$
   $$\mathcal{Z}\{x[-n]\} = \sum_{n=-\infty}^{\infty} x[-n]z^{-n}$$
   $$= \sum_{m=-\infty}^{\infty} x[m]z^{m} \quad \text{where } m = -n$$
   $$= \sum_{m=-\infty}^{\infty} x[m](z^{-1})^{-m}$$
   $$= X(z^{-1}) \quad \text{ROC:} \quad r_1 < |z^{-1}| < r_2$$

Digital Signal Processing Answers

Jonathan M Blackledge

Digital Signal Processing Answers:

Digital Signal Processing Richard A. Roberts,Clifford T. Mullis,1987-01 **Digital Signal Processing: A Practical Guide for Engineers and Scientists** Steven Smith,2013-10-22 In addition to its thorough coverage of DSP design and programming techniques Smith also covers the operation and usage of DSP chips He uses Analog Devices popular DSP chip family as design examples Covers all major DSP topics Full of insider information and shortcuts Basic techniques and algorithms explained without complex numbers Digital Signal Processing Alan V. Oppenheim,Ronald W. Schafer,Harlan Hersey,Syed Hamid Nawab,1976 **Solutions Manual, Digital Signal Processing** William D. Stanley,Ronald W. Schafer,1975 *Digital Signal Processing* Thomas J. Cavicchi,2000 What are the relations between continuous time and discrete time sampled data systems signals and their spectra How can digital systems be designed to replace existing analog systems What is the reason for having so many transforms and how do you know which one to use What do s and z really means and how are they related How can you use the fast Fourier transform FFT and other digital signal processing DSP algorithms to successfully process sampled signals Inside you ll find the answers to these and other fundamental questions on DSP You ll gain a solid understanding of the key principles that will help you compare select and properly use existing DSP algorithms for an application You ll also learn how to create original working algorithms or conceptual insights design frequency selective and optimal digital filters participate in DSP research and select or construct appropriate hardware implementations Key Features MATLAB graphics are integrated throughout the text to help clarify DSP concepts Complete numerical examples clearly illustrate the practical uses of DSP Uniquely detailed coverage of fundamental DSP principles provides the rationales behind definitions algorithms and transform properties Practical real world examples combined with a student friendly writing style enhance the material Unexpected results and thought provoking questions are provided to further spark reader interest Over 525 end of chapter problems are included with complete solutions available to the instructor 168 are MATLAB oriented **Digital Signal Processing** Li Tan,Jean Jiang,2018-10-02 Digital Signal Processing Fundamentals and Applications Third Edition not only introduces students to the fundamental principles of DSP it also provides a working knowledge that they take with them into their engineering careers Many instructive worked examples are used to illustrate the material and the use of mathematics is minimized for an easier grasp of concepts As such this title is also useful as a reference for non engineering students and practicing engineers The book goes beyond DSP theory showing the implementation of algorithms in hardware and software Additional topics covered include adaptive filtering with noise reduction and echo cancellations speech compression signal sampling digital filter realizations filter design multimedia applications over sampling etc More advanced topics are also covered such as adaptive filters speech compression such as PCM law ADPCM and multi rate DSP over sampling ADC subband coding and wavelet transform Covers DSP principles with an emphasis on communications and control applications Includes chapter objectives worked examples and end of chapter

exercises that aid the reader in grasping key concepts and solving related problems Provides an accompanying website with MATLAB programs for simulation and C programs for real time DSP Presents new problems of varying types and difficulties

Digital Signal Processing 101 Michael Parker,2017-06-28 Digital Signal Processing 101 Everything You Need to Know to Get Started provides a basic tutorial on digital signal processing DSP Beginning with discussions of numerical representation and complex numbers and exponentials it goes on to explain difficult concepts such as sampling aliasing imaginary numbers and frequency response It does so using easy to understand examples with minimum mathematics In addition there is an overview of the DSP functions and implementation used in several DSP intensive fields or applications from error correction to CDMA mobile communication to airborne radar systems This book has been updated to include the latest developments in Digital Signal Processing and has eight new chapters on Automotive Radar Signal Processing Space Time Adaptive Processing Radar Field Orientated Motor Control Matrix Inversion algorithms GPUs for computing Machine Learning Entropy and Predictive Coding Video compression Features eight new chapters on Automotive Radar Signal Processing Space Time Adaptive Processing Radar Field Orientated Motor Control Matrix Inversion algorithms GPUs for computing Machine Learning Entropy and Predictive Coding and Video compression Provides clear examples and a non mathematical approach to get you up to speed quickly Includes an overview of the DSP functions and implementation used in typical DSP intensive applications including error correction CDMA mobile communication and radar systems *Digital Signal Processing* D. Sundararajan,2003 The key features include emphasis on the use of the discrete Fourier transform and comprehensive coverage of the design of commonly used digital filters Digital Signal Processing Sanjeev Sharma,2025-06-01 **Solutions Manual for Digital Signal Processing with Examples in Matlab** Samuel D. Stearns,2002-10 **Understanding Digital Signal Processing with MATLAB® and Solutions** Alexander D. Poularikas,2017-11-13 The book discusses receiving signals that most electrical engineers detect and study The vast majority of signals could never be detected due to random additive signals known as noise that distorts them or completely overshadows them Such examples include an audio signal of the pilot communicating with the ground over the engine noise or a bioengineer listening for a fetus heartbeat over the mother s The text presents the methods for extracting the desired signals from the noise Each new development includes examples and exercises that use MATLAB to provide the answer in graphic forms for the reader s comprehension and understanding **Digital Signal Processing** Samir I. Abood,2020-01-20 Digital Signal Processing A Primer with MATLAB provides excellent coverage of discrete time signals and systems At the beginning of each chapter an abstract states the chapter objectives All principles are also presented in a lucid logical step by step approach As much as possible the authors avoid wordiness and detail overload that could hide concepts and impede understanding In recognition of requirements by the Accreditation Board for Engineering and Technology ABET on integrating computer tools the use of MATLAB is encouraged in a student friendly manner MATLAB is introduced in

Appendix C and applied gradually throughout the book Each illustrative example is immediately followed by practice problems along with its answer Students can follow the example step by step to solve the practice problems without flipping pages or looking at the end of the book for answers These practice problems test students comprehension and reinforce key concepts before moving onto the next section Toward the end of each chapter the authors discuss some application aspects of the concepts covered in the chapter The material covered in the chapter is applied to at least one or two practical problems It helps students see how the concepts are used in real life situations Also thoroughly worked examples are given liberally at the end of every section These examples give students a solid grasp of the solutions as well as the confidence to solve similar problems themselves Some of hte problems are solved in two or three ways to facilitate a deeper understanding and comparison of different approaches Designed for a three hour semester course Digital Signal Processing A Primer with MATLAB is intended as a textbook for a senior level undergraduate student in electrical and computer engineering The prerequisites for a course based on this book are knowledge of standard mathematics including calculus and complex numbers **Digital Signal Processing** EduGorilla Prep Experts,2024-07-25 EduGorilla Publication is a trusted name in the education sector committed to empowering learners with high quality study materials and resources Specializing in competitive exams and academic support EduGorilla provides comprehensive and well structured content tailored to meet the needs of students across various streams and levels **Digital Signal Processing** Jonathan M Blackledge,2006-03-01 This book forms the first part of a complete MSc course in an area that is fundamental to the continuing revolution in information technology and communication systems Massively exhaustive authoritative comprehensive and reinforced with software this is an introduction to modern methods in the developing field of Digital Signal Processing DSP The focus is on the design of algorithms and the processing of digital signals in areas of communications and control providing the reader with a comprehensive introduction to the underlying principles and mathematical models Provides an introduction to modern methods in the developing field of Digital Signal Processing DSP Focuses on the design of algorithms and the processing of digital signals in areas of communications and control Provides a comprehensive introduction to the underlying principles and mathematical models of Digital Signal Processing **Digital Signal Processing** Rulph Chassaing,1998-11-16 A practical guide to using the TMS320C31 DSP Starter Kit With applications and demand for high performing digital signalprocessors expanding rapidly it is becoming increasingly importantfor today s students and practicing engineers to master real timedigital signal processing DSP techniques Digital Signal Processing Laboratory Experiments Using C and theTMS320C31 DSK offers users a practical and economicalm approachto understanding DSP principles designs and applications Demonstrating Texas Instruments TI state of the art low pricedDSP Starter Kit DSK this book clearly illustrates and integratespractical aspects of real time DSP implementation techniques andcomplex DSP concepts into lab exercises and experiments TI sTMS320C31 digital signal processor provides substantial performancebenefits for designs that have floating

point capabilitiessupported by high level language compilers Most chapters begin with a theoretical discussion followed byrepresentative examples With numerous programming examples usingTMS320C3x and C code included on disk this easy to read text Covers DSK tools the architecture and instructions for theTMS320C31 processor Illustrates input and output Introduces the z transform Discusses finite impulse response FIR filters including theeffect of window functions Covers infinite impulse response IIR filters Discusses the development and implementation of the fast Fouriertransform FFT Examines utility of adaptive filters for differentapplications Bridging the gap between theory and application this bookfurnishes a solid foundation for DSP lab or project design coursesfor students and serves as a welcome practically oriented tutorialin the latest DSP techniques for working professionals Digital Signal Processors and Their Applications Mr. Rohit Manglik,2023-06-23 This subject thoroughly investigates digital signal processors and their applications covering its foundational theories analytical methodologies and real world implementations It provides a deep dive into the domain with illustrative case studies **Modern Digital Signal Processing** V. Udayashankara,2016-02-29 Intended as a text for three courses Signals and Systems Digital Signal Processing DSP and DSP Architecture this comprehensive book now in its Third Edition continues to provide a thorough understanding of digital signal processing beginning from the fundamentals to the implementation of algorithms on a digital signal processor This Edition includes Assembly C and real time C programs for TMS 320C54XX and 320C6713 processor which are useful to conduct a laboratory course in Digital Signal Processing Besides many existing chapters are modified substantially to widen the coverage of the book Primarily designed for undergraduate students of Electronics and Communication Engineering Electronics and Instrumentation Engineering Electrical and Electronics Engineering Instrumentation and Control Engineering Computer Science and Information Science this text will also be useful for advanced digital signal processing and real time digital signal processing courses of postgraduate programmes **Starting Digital Signal Processing in Telecommunication Engineering** Tomasz P. Zieliński,2021-01-29 This hands on laboratory driven textbook helps readers understand principles of digital signal processing DSP and basics of software based digital communication particularly software defined networks SDN and software defined radio SDR In the book only the most important concepts are presented Each book chapter is an introduction to computer laboratory and is accompanied by complete laboratory exercises and ready to go Matlab programs with figures and comments available at the book webpage and running also in GNU Octave 5 2 with free software packages showing all or most details of relevant algorithms Students are tasked to understand programs modify them and apply presented concepts to recorded real RF signal or simulated received signals with modelled transmission condition and hardware imperfections Teaching is done by showing examples and their modifications to different real world telecommunication like applications The book consists of three parts introduction to DSP spectral analysis and digital filtering introduction to DSP advanced topics multi rate adaptive model based and multimedia speech audio video signal analysis and processing and introduction to

software defined modern telecommunication systems SDR technology analog and digital modulations single and multi carrier systems channel estimation and correction as well as synchronization issues Many real signals are processed in the book in the first part mainly speech and audio while in the second part mainly RF recordings taken from RTL SDR USB stick and ADALM PLUTO module for example captured IQ data of VOR avionics signal classical FM radio with RDS digital DAB DAB radio and 4G LTE digital telephony Additionally modelling and simulation of some transmission scenarios are tested in software in the book in particular TETRA ADSL and 5G signals Provides an introduction to digital signal processing and software based digital communication Presents a transition from digital signal processing to software defined telecommunication Features a suite of pedagogical materials including a laboratory test bed and computer exercises experiments **MATLAB/Simulink for Digital Signal Processing** Won Y. Yang,2015-03-02 Chapter 1 Fourier Analysis 1 1 1 CTFS CTFT DTFT AND DFS DFT 1 1 2 SAMPLING THEOREM 16 1 3 FAST FOURIER TRANSFORM FFT 19 1 3 1 Decimation in Time DIT FFT 19 1 3 2 Decimation in Frequency DIF FFT 22 1 3 3 Computation of IDFT Using FFT Algorithm 23 1 4 INTERPRETATION OF DFT RESULTS 23 1 5 EFFECTS OF SIGNAL OPERATIONS ON DFT SPECTRUM 31 1 6 SHORT TIME FOURIER TRANSFORM STFT 32 Chapter 2 System Function Impulse Response and Frequency Response 51 2 1 THE INPUT OUTPUT RELATIONSHIP OF A DISCRETE TIME LTI SYSTEM 52 2 1 1 Convolution 52 2 1 2 System Function and Frequency Response 54 2 1 3 Time Response 55 2 2 COMPUTATION OF LINEAR CONVOLUTION USING DFT 55 2 3 PHYSICAL MEANING OF SYSTEM FUNCTION AND FREQUENCY RESPONSE 58 Chapter 3 Correlation and Power Spectrum 73 3 1 CORRELATION SEQUENCE 73 3 1 1 Crosscorrelation 73 3 1 2 Autocorrelation 76 3 1 3 Matched Filter 80 3 2 POWER SPECTRAL DENSITY PSD 83 3 2 1 Periodogram PSD Estimator 84 3 2 2 Correlogram PSD Estimator 85 3 2 3 Physical Meaning of Periodogram 85 3 3 POWER SPECTRUM FREQUENCY RESPONSE AND COHERENCE 89 3 3 1 PSD and Frequency Response 90 3 3 2 PSD and Coherence 91 3 4 COMPUTATION OF CORRELATION USING DFT 94 Chapter 4 Digital Filter Structure 99 4 1 INTRODUCTION 99 4 2 DIRECT STRUCTURE 101 4 2 1 Cascade Form 102 4 2 2 Parallel Form 102 4 3 LATTICE STRUCTURE 104 4 3 1 Recursive Lattice Form 106 4 3 2 Nonrecursive Lattice Form 112 4 4 LINEAR PHASE FIR STRUCTURE 114 4 4 1 FIR Filter with Symmetric Coefficients 115 4 4 2 FIR Filter with Anti Symmetric Coefficients 115 4 5 FREQUENCY SAMPLING FRS STRUCTURE 118 4 5 1 Recursive FRS Form 118 4 5 2 Nonrecursive FRS Form 124 4 6 FILTER STRUCTURES IN MATLAB 126 4 7 SUMMARY 130 Chapter 5 Filter Design 137 5 1 ANALOG FILTER DESIGN 137 5 2 DISCRETIZATION OF ANALOG FILTER 145 5 2 1 Impulse Invariant Transformation 145 5 2 2 Step Invariant Transformation Z O H Zero Order Hold Equivalent 146 5 2 3 Bilinear Transformation BLT 147 5 3 DIGITAL FILTER DESIGN 150 5 3 1 IIR Filter Design 151 5 3 2 FIR Filter Design 160 5 4 FDATOOL 171 5 4 1 Importing Exporting a Filter Design Object 172 5 4 2 Filter Structure Conversion 174 5 5 FINITE WORDLENGTH EFFECT 180 5 5 1 Quantization Error 180 5 5 2 Coefficient Quantization 182 5 5 3 Limit Cycle 185 5 6 FILTER DESIGN TOOLBOX 193 Chapter 6 Spectral

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Foundations of Digital Signal Processing Patrick Gaydecki,2004 This book covers the basic theoretical algorithmic and real time aspects of digital signal processing DSP Detailed information is provided on off line real time and DSP programming and the reader is effortlessly guided through advanced topics such as DSP hardware design FIR and IIR filter design and difference equation manipulation

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