

Series Editor: R.W. Lucky

# COMMUNICATION SYSTEM DESIGN USING DSP ALGORITHMS

With Laboratory Experiments  
for the TMS320C30

**STEVEN A. TRETTER**

Progressive Exhibit 2019  
Liberty Mutual v.  
Progressive  
CBM2013-00009

Library of Congress Cataloging-in-Publication Data

---

Tretter, Steven A.

Communication system design using DSP algorithms : with laboratory experiments for the TMS320C30 / Steven A. Tretter.

p. cm. -- (Applications of communications theory)

Includes bibliographical references and index.

ISBN 0-306-45032-1

1. Signal processing--Digital techniques. 2. Digital communications--Equipment and supplies--Design--Data processing. 3. Texas Instruments TMS320 series microprocessors. 4. Real-time data processing. I. Title. II. Series.

TK5102.9.T74 1995

621.382'2'078--dc20

95-36860

CIP

---

If your diskette is defective in manufacture or has been damaged in transit, it will be replaced at no charge if returned within 30 days of receipt to Managing Editor, Plenum Press, 233 Spring Street, New York, NY 10013.

The publisher makes no warranty of any kind, expressed or implied, with regard to the software reproduced on the diskette or the accompanying documentation. The publisher shall not be liable in any event for incidental or consequential damages or loss in connection with, or arising out of, the furnishing, performance, or use of the software.

ISBN 0-306-45032-1

©1995 Plenum Press, New York  
A Division of Plenum Publishing Corporation  
233 Spring Street, New York, N.Y. 10013

10 9 8 7 6 5 4 3

All rights reserved

No part of this book may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording, or otherwise, without written permission from the Publisher

Printed in the United States of America

# Contents

|   |           |
|---|-----------|
| <b>1. Brief Overview of the Hardware and Software Tools</b> .....   | <b>1</b>  |
| 1.1. Some DSP Chip History and Typical Applications .....   | 1         |
| 1.2. Introduction to the TMS320C30 Floating-Point DSP .....   | 3         |
| 1.2.1. The Central Processing Unit (CPU) .....  | 5         |
| 1.2.2. Memory Organization .....  | 5         |
| 1.2.3. The Internal Bus .....   | 6         |
| 1.2.4. The External Buses and Interrupts .....  | 6         |
| 1.2.5. Peripherals .....  | 6         |
| 1.2.6. The Direct Memory Access (DMA) Controller .....  | 6         |
| 1.2.7. Brief Description of the Instruction Set .....   | 6         |
| 1.3. The TMS320C30 Evaluation Module .....  | 7         |
| 1.4. Software Tools .....   | 8         |
| 1.4.1. Software Supplied by Texas Instruments .....   | 9         |
| 1.4.2. Digital Filter Design Programs .....   | 10        |
| 1.4.3. Other Software .....   | 11        |
| 1.5. Introductory Experiments .....   | 11        |
| <b>2. Learning to Use the Hardware and Software Tools by Generating a Sine Wave</b> .....   | <b>13</b> |
| 2.1. Some Basic Utility Files, Programs, and Environment Variables Required by the TMS320C30<br>Assembler, C Compiler, and Linker ..... | 13        |
| 2.2. Method 1 for Generating a Sine Wave .....  | 17        |
| 2.3. Method 2 for Generating a Sine Wave—Using Interrupts .....   | 24        |
| 2.4. Method 3—DMA from a Table .....  | 26        |

|  |           |
|--|-----------|
| 3.1. Discrete-Time Convolution and Frequency Responses .....   | 29        |
| 3.2. Finite Duration Impulse Response (FIR) Filters .....  | 30        |
| 3.2.1. Block Diagram for Most Common Realization .....   | 30        |
| 3.2.2. Two Methods for Finding the Filter Coefficients to Achieve a Desired Frequency Response ...         | 30        |
| 3.2.3. Using Circular Buffers to Implement FIR Filters .....   | 32        |
| 3.2.4. How to Make an Assembly Language Convolution Function that Is Called from and Returns to C .....    | 36        |
| 3.3. Infinite Duration Impulse Response (IIR) Filters .....  | 40        |
| 3.3.1. Realizations for IIR Filters .....  | 40        |
| 3.3.2. A Program for Designing IIR Filters .....   | 41        |
| 3.3.3. Two Methods for Measuring a Phase Response .....  | 42        |
| 3.4. Hardware Details and Laboratory Experiments for FIR and IIR Digital Filters .....                     | 44        |
| 3.4.1. Some Hardware and Software Details for the EVM .....  | 44        |
| 3.4.2. Measuring the Time to Execute a Program Segment by Using the Benchmarking Capability of EVM30 ..... | 46        |
| 3.4.3. Laboratory Experiments for FIR Filters .....  | 47        |
| 3.4.4. Laboratory Experiments for IIR Filters .....  | 49        |
| 3.5. Additional References .....   | 49        |
| <br>   |           |
| <b>4. The FFT and Power Spectrum Estimation .....</b>  | <b>51</b> |
| 4.1. The Discrete-Time Fourier Transform .....   | 51        |
| 4.2. Data Window Functions .....   | 51        |
| 4.3. The Discrete Fourier Transform and Its Inverse .....  | 52        |
| 4.4. The Fast Fourier Transform .....  | 53        |
| 4.5. Using the FFT to Estimate a Power Spectrum .....  | 54        |
| 4.6. Laboratory Experiments .....  | 60        |
| 4.6.1. FFT Experiments .....   | 60        |
| 4.6.2. Experiments for Power Spectrum Estimation .....   | 60        |
| 4.7. Additional References .....   | 63        |
| <br>   |           |
| <b>5. Amplitude Modulation .....</b>   | <b>65</b> |
| 5.1. Theoretical Description of Amplitude Modulation .....   | 65        |
| 5.1.1. Mathematical Formula for an AM Signal .....   | 65        |
| 5.1.2. Example for Single Tone Modulation .....  | 65        |
| 5.1.3. The Spectrum of an AM Signal .....  | 66        |
| 5.2. Demodulating an AM Signal by Envelope Detection .....   | 66        |
| 5.2.1. Square-Law Demodulation of AM Signals .....   | 66        |
| 5.2.2. Hilbert Transforms and the Complex Envelope .....   | 67        |
| 5.3. Laboratory Experiments for AM Modulation and Demodulation .....                                       | 69        |
| 5.3.1. Making an AM Modulator .....  | 69        |
| 5.3.2. Making a Square-Law Envelope Detector .....   | 69        |
| 5.3.3. Making an Envelope Detector Using the Hilbert Transform .....                                       | 70        |
| 5.4. Additional References .....   | 71        |



|   |           |
|---|-----------|
| 6.1. Mathematical Description of the DSBSC-AM Signal .....  | 73        |
| 6.2. The Ideal Coherent Receiver .....  | 73        |
| 6.3. The Costas Loop as a Practical Approach to Coherent Demodulation .....   | 74        |
| 6.4. Laboratory Exercises and Experiments for the Costas Loop .....   | 76        |
| 6.4.1. Theoretical Design Exercises .....   | 77        |
| 6.4.2. Hardware Experiments .....   | 78        |
| 6.5. Additional References .....  | 78        |
| <br>  |           |
| <b>7. Single-Sideband Modulation and Frequency Translation .....</b>  | <b>79</b> |
| 7.1. Single-Sideband Modulators .....   | 79        |
| 7.2. Coherent Demodulation of SSB Signals .....   | 80        |
| 7.3. Frequency Translation .....  | 81        |
| 7.4. Laboratory Experiments .....   | 82        |
| 7.4.1. Making an SSB Modulator .....  | 82        |
| 7.4.2. Coherent Demodulation of an SSB Signal .....   | 82        |
| 7.5. Additional References .....  | 83        |
| <br>  |           |
| <b>8. Frequency Modulation .....</b>  | <b>85</b> |
| 8.1. The FM Signal and Some of Its Properties .....   | 85        |
| 8.1.1. Definition of Instantaneous Frequency and the FM Signal .....  | 85        |
| 8.1.2. Single Tone FM Modulation .....  | 86        |
| 8.1.3. Narrow Band FM Modulation .....  | 86        |
| 8.1.4. The Bandwidth of an FM Signal .....  | 86        |
| 8.2. FM Demodulation by a Frequency Discriminator .....   | 86        |
| 8.3. Using a Phase-Locked Loop for FM Demodulation .....  | 87        |
| 8.4. Laboratory Experiments for Frequency Modulation .....  | 89        |
| 8.4.1. Experimentally Measuring the Spectrum of an FM Signal .....  | 89        |
| 8.4.2. FM Demodulation Using a Frequency Discriminator .....  | 90        |
| 8.4.3. Using a Phase-Locked Loop for FM Demodulation .....  | 90        |
| 8.5. Additional References .....  | 90        |
| <br>  |           |
| <b>9. Pseudo-Random Binary Sequences and Data Scramblers .....</b>  | <b>91</b> |
| 9.1. Using Linear Feedback Shift Registers to Generate Pseudo-Random Binary Sequences .....                                   | 91        |
| 9.1.1. The Linear Feedback Shift Register Sequence Generator .....  | 92        |
| 9.1.2. The Connection Polynomial and Sequence Period .....  | 92        |
| 9.1.3. Properties of Maximal Length Sequences .....   | 93        |
| 9.2. Self Synchronizing Data Scramblers .....   | 93        |
| 9.2.1. The Scrambler .....  | 93        |
| 9.2.2. The Descrambler .....  | 94        |
| 9.3. Theoretical and Simulation Exercises for Shift Register Sequence Generators and Scramblers .....                         | 94        |
| 9.3.1. Exercises for a Shift Register Sequence Generator with a Primitive Connection Polynomial ...                           | 95        |
| 9.3.2. Exercises for a Shift Register Sequence Generator with an Irreducible but not Primitive<br>Connection Polynomial ..... | 95        |
| 9.3.3. Exercises for a Shift Register Sequence Generator with a Reducible Connection Polynomial ..                            | 95        |
| 9.4. Additional References .....  | 96        |

# Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

## Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

## Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

## Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

## API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

## LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

## FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

## E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.