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CARRIER ESTIMATION USING CLASSIC SPECTRAL ESTIMATION TECHNIQUES FOR THE PROPOSED DEMAND ASSIGNMENT MULTIPLE ACCESS SERVICE

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CARRIER ESTIMATION USING CLASSIC SPECTRAL ESTIMATION TECHNIQUES FOR THE PROPOSED DEMAND ASSIGNMENT MULTIPLE ACCESS SERVICE

BY

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ABSTRACT
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In any satellite communication, the Doppler shift associated with the satellite's position and velocity must be calculated in order to determine the carrier frequency. If the satellite state vector is unknown then some estimate must be formed of the Doppler-shifted carrier frequency. One elementary technique is to examine the signal spectrum and base the estimate on the dominant spectral component. If, however, the carrier is spread (as in most satellite communications) this technique may fail unless the chip rate-to-data rate ratio (processing gain) associated with the carrier is small.
In this case, there may be enough spectral energy to allow peak detection against a noise background.

In this thesis, we present a method to estimate the frequency (without knowledge of the Doppler shift) of a spread-spectrum carrier assuming a small processing gain and binary-phase shift keying (BPSK) modulation. Our method relies on an averaged discrete Fourier transform along with peak detection on spectral match filtered data. We provide theory and simulation results indicating the accuracy of this method. In addition, we will describe an all-digital hardware design based around a Motorola DSP56303 and high-speed A/D which implements this technique in real-time. The hardware design is to be used in NMSU’s implementation of NASA’s demand assignment, multiple access (DAMA) service.
Contents

List of Figures ix
List of Tables xi
Frequently Used Terminology xii

1 Overview 1

1.1 Introduction ............................................. 1
1.2 Comparison of Goddard and NMSU’s DAMA Proposals ... 2
1.3 Proposed Solution ...................................... 3
1.4 Simulations, Test Data, and Theory ..................... 4
1.5 DAMA Hardware ........................................ 6

2 DAMA Project Description 8

2.1 Current WSC Operations ............................... 8
2.2 NMSU’s Proposal ........................................ 10
2.3 Spread Spectrum Fundamentals ......................... 12
2.4 Operating Parameters Description ..................... 16
2.5 Carrier Estimation Problem ........................... 18
2.6 Proposed Solution ...................................... 19

3 Theory and Simulation 24

3.1 Signal Description ....................................... 24
3.2 Estimation Accuracy Theory ........................... 25
3.3 Comparison of Theory to Simulation .................. 29
3.4 Simulation Model Description ......................... 31
3.5 Simulation Results .................................. 32
3.6 Theoretical/Simulation Data Summary ............... 38

4 WSC Data Collection Experiment ...................... 39
  4.1 Motivation of WSC Data Collection Experiment ...... 39
  4.2 Data Collection Setup ................................ 40
  4.3 WSC Collected Data Processing ....................... 43
  4.4 WSC Data Results Compared to Simulation ........... 44
  4.5 Conclusions of WSC Data Collection ................. 46

5 Carrier Estimation Hardware and Software ............ 48
  5.1 Motorola DSP56303EVM Description .................. 48
  5.2 Burr Brown 800kHz A/D .............................. 51
  5.3 A/D Interface Board .................................. 51
  5.4 Additional Hardware .................................. 52
  5.5 Software Description for Real-Time Carrier Estimation ... 53

6 Conclusions and Future Work ............................ 56

A Matlab Simulation Code .................................. 57
B Motorola DSP 56303EVM Code ......................... 94

References .................................................. 134
# List of Figures

2.1 Illustration of Doppler Shift to DAMA Carrier .................. 9
2.2 DAMA Carrier Placement Against MA Spectrum .................. 12
2.3 TDRSS MA Spectrum at IF from Actual Data ................. 13
2.4 2047 PN Code Implementation ................................. 14
2.5 Spreading Effect of Processing Gains ....................... 16
2.6 Flowchart for Carrier Estimation Algorithm ............... 23
3.1 Signal Space Diagram for BPSK ................................. 25
3.2 Comparison of Theoretical Curve Against Simulation ....... 30
3.3 Family of Curves for Non-SMF Case ....................... 33
3.4 Non-SMF Frequency Estimation for PG = 10, SNR = 2 dB ..... 34
3.5 Non-SMF Frequency Estimation for PG = 20, SNR = 2 dB ..... 34
3.6 Non-SMF Frequency Estimation for PG = 100, SNR = 2 dB ... 35
3.7 Family of Curves for SMF Case ................................. 35
3.8 SMF Frequency Estimation for PG = 10, SNR = 2 dB .......... 36
3.9 SMF Frequency Estimation for PG = 40, SNR = 2 dB .......... 37
3.10 SMF Frequency Estimation for PG = 100, SNR = 2 dB ...... 37
4.1 Experiment Setup ............................................. 40
4.2 Placement of Test Frequencies Near TDRSS Null .............. 42
4.3 Comparison of Simulated Results vs. WSC Captured Data .... 45
4.4 Carrier Estimation Summary ................................. 47

5.1 DSP56300 Core System Block Diagram ........................ 49

5.2 Locking Tone Generation ........................................ 53
List of Tables

1  Test Sets Captured ................................. 43
Frequently Used Terminology

• AWGN: Additive White Gaussian Noise

• BPSK: Binary Phase Shift Keying(ed)

• BW: Bandwidth

• CDMA: Code Division Multiple Access

• DAMA: Demand Access Multiple Assignment

• DSO: Digital Storage Oscilloscope

• DSP: Digital Signal Processing/Processor

• MA: Multiple Access

• PG: Processing Gain

• PN: Psuedo-Noise

• PSD: Power Spectral Density

• Rx: Receive

• SMF: Spectral Matched Filter

• SN: Space Network

• SNR: Signal to Noise Ratio
• SS: Spread Spectrum

• TDMA: Time Division Multiple Access

• TDRS: Tracking and Data Relay Satellite

• TDRSS: Tracking and Data Relay Satellite System

• Tx: Transmit

• WSC: NASA’s White Sands Complex
1 Overview

1.1 Introduction

In an effort to provide increased access to NASA's Space Network (SN), a Demand Access Multiple Assignment communication scheme has been proposed. Under this scheme, users would have the option to communicate short information packets at low data rates on demand. This scheme is driven by the increased ability of modern satellites (spacecraft) to detect error conditions on board the satellite [1]. Under current SN operations, communication services are pre-scheduled and the schedules often have significant delay and are not easily modified. The DAMA service is to be designed such that it operates independently of the current scheduled Multiple Access (MA) service.

The SN consists of geostationary Tracking and Data Relay Satellites (TDRS) that operate as a virtual "radio frequency (RF) mirror" for data transmissions from/to low Earth orbiting (LEO) spacecraft communicating to/from ground stations. These LEO spacecraft are in orbit about the earth and due to their relative motion to a receiving TDRS, a Doppler shift is induced in transmissions. Since the MA service is pre-scheduled, these Doppler shifts may be accounted for allowing the ground station to detect and receive the LEO signal. In the case of the DAMA system, where data transmissions are to be scheduled on demand,
the Doppler shift information may be unknown and thus a system must be de­
signed to estimate (to within ±3 kHz) the carrier of the LEO signals.

1.2 Comparison of Goddard and NMSU's DAMA Proposals

Two independent proposals have been offered to implement the DAMA ser­
vie. The first has been proposed by NASA/Goddard Space Flight Center (GSF) and the second by New Mexico State University. The Goddard proposal intends to provide continuous tracking of all LEO satellites equipped with DAMA capabil­
ity. Thus with the state vectors of all of these LEO satellites known, the Doppler shift of the carrier can be computed much like for the MA service. Whereas the Goddard proposal must maintain these state vectors so that the ground station receiver may demodulate, the NMSU proposal forgoes LEO satellite state vec­
tor knowledge to simplify the required ground station hardware. In the NMSU proposal only a single element of the TDRS antenna array is used as a global bea­
con [1]. With a global beacon configuration, even a satellite that is experiencing alignment problems may transmit an emergency message to ground station users utilizing the DAMA communication system. As the state vector of the commun­cating spacecraft has been given up, the ground station will not know the position of transmitting LEO space vehicle and thus the Doppler shift cannot be accounted for [2]. Previous work has shown that the Doppler shift of a LEO spacecraft and
A TDRSS can vary by as much as ±50 kHz which is outside of the ground station receiver (GSR) tolerance of ±3 kHz [3].

The fundamental problem to NMSU's proposal lies with estimating the carrier of the transmitted signal to within the tolerance of the GSR. Hardware must be developed that will provide a locking tone, accurate to within the ground station tolerance, in order for the ground station to demodulate. The problem is exacerbated by the nature of the DAMA signal. The DAMA carrier is to employ a Spread Spectrum (SS) scheme. SS signals tend to suppress spectral peaks of carriers and have responses that are spread out over a wider bandwidth. As we shall show below, this makes the proposed solution to carrier estimation more difficult.

1.3 Proposed Solution

The proposed solution to the carrier estimation problem described above is to employ classical Digital Signal Processing (DSP) spectral estimation techniques to estimate the carrier frequency. We shall employ a Discrete Fourier Transform (DFT) to generate magnitude squared spectral data from the received signal. The resolution of the DFT will be set to provide accuracy to within the ground station tolerance. A single iteration of this process will not be sufficient to protect the carrier estimation from noise so we will average the magnitude squared data to limit the effects of noise. This process results in a periodogram. Having obtained the
periodogram of the received signal, we shall employ a frequency domain matched
filter to maximize the Spectrum-to-Noise ratio (SPNR). The frequency domain
matched filter will be predetermined based primarily upon the predefined SS fre-
quency characteristics, such as processing gain (PG) and power, of the received
signal. The results of the application of the matched filter, like those of the time
domain equivalent, provide an optimal solution by enhancing the spectrum prior
to searching. We then search the enhanced periodogram for a peak with which
we base our carrier estimation. The accuracy of this technique will be shown
to depend primarily on the PG of the DAMA carrier and the Signal-to-Noise
ratio(SNR).

1.4 Simulations, Test Data, and Theory

At the core of the proof of concept for the proposed solution is a simulation
model designed in Matlab. The simulation models the DAMA carrier against
additive white Gaussian noise (AWGN), where we use AWGN to effectively model
the white noise like spectrum of the MA service [2]. Having approximated the
TDRSS channel by its most critical feature(presence of the MA service) we add the
DAMA carrier and simulate carrier estimation based upon the approach described
in section 1.3. The simulation model provides estimation accuracy as a function of
the SNR and the PG of the DAMA carrier. We will show that accurate estimation,
to within the ground station tolerance, is achievable 80%-90% of the time for the given DAMA data rates and corresponding spreading rates.

To verify the accuracy of the simulation model, we include the results of an experiment with test data gathered at NASA's White Sands Complex (WSC). In this experiment, actual data vectors were streamed to a ground station transmitter for transmission to a TDRS (in orbit) and sent back to the ground station receiver. The parameters of the experiment were set such that we could observe several key issues with carrier estimation. The data gathered was processed with the proposed algorithm and compared to simulation results. The most significant conclusion of the experiment was that carrier estimation with the collected data was nearly equivalent to results obtained through simulation. The simulation is then recognized to accurately model the actual TDRSS channel.

We have developed a theoretical analysis that leads to a rough approximation for carrier estimation accuracy. The analysis of carrier frequency estimation is based upon use of the DFT, and the description of carrier estimation accuracy as a random variable [4]. From this description and the use of various approximations, we obtain an expression that describes the root mean square error (RMSE) between the actual carrier frequency and the estimate. The result is expressed as a function of SNR, data (chip) rate, and window type and length. Though the approximations break down in low SNR cases, in the higher SNR cases theory agrees with simulation results.
1.5 DAMA Hardware

As described above, we seek to provide the ground station with an accurate carrier frequency based upon our estimation. We perform this estimation through the use of specifically designed hardware. The base of the hardware utilizes Motorola’s DSP56303EVM (EVM). The EVM utilizes Motorola’s DSP56300 core which is capable of 80 million instructions per second at 80 MHz and has enough available on-chip memory to implement the algorithm described above. As we will be required to sample the incoming signals at rates greater than that allowed by the EVM, we have integrated an 800 kHz 12 bit Burr-Brown ADS7810/19 analog to digital converter (A/D) into the design. To interface the EVM and the A/D requires some additional logic and level translators that are implemented on an additional interface card. The card allows the EVM to control the A/D while allowing samples from the A/D to be passed directly into the memory of the EVM for processing. These three components, excluding some additional analog pre-processing and post-processing equipment, make up the core of the carrier estimation hardware. The hardware is designed to receive signals that have been filtered and frequency shifted to baseband, estimate the carrier, and then provide a locking tone to the GSR. The GSR will use this carrier estimate to demodulate the DAMA carrier.
The hardware has been tested with synthesized waveforms as well as actual waveforms captured during the WSC experiment and performs as designed/required.
2 DAMA Project Description

2.1 Current WSC Operations

TDRSS was originally devised by NASA as an efficient means to control costs associated with providing a ground station for each satellite [5]. The concept of a space network was formed where users could transmit and receive all communications through a common ground station. NASA operates TDRSS as a space network (SN) using it to provide customers with communication access to their Low Earth Orbiting (LEO) spacecraft. The SN consists of six geostationary Tracking and Data Relay Satellites (TDRS) located 22,250 miles in orbit and a ground station located at the WSC (other operational ground stations exist as well) [5]. The function of a TDRS is to act as a virtual “RF mirror” through which communication signals are relayed between user spacecraft and the ground station. An antenna array, located on each TDRS, is tuned by weighting antenna elements to provide a spot beacon to the spacecraft. This requires a unique weighting vector and associated signal processing equipment for each user spacecraft [1]. Two communication schemes are used by the SN to fulfill various communication needs [5] [3]:

- multiple access (MA) at low data rates of 100 bps to 50 kbps operating in the S-band (2.1031 GHz - 2.1097 GHz forward service, 2.2845 GHz - 2.2905 GHz return) and using CDMA spread spectrum with a chip rate of 3 Mchips/s.
single access (SA) at up to 300 kbps operating in either the S-band or the K-band (2.0204 GHz - 2.1233 GHz forward service, 2.2 GHz - 2.3 GHz return) using TDMA.

The SN is able to provide 80% - 100% coverage for LEO spacecraft and is capable of simultaneously supporting 26 user spacecraft.

TDRSS consists of geostationary satellites but the LEO spacecraft that use this system are not necessarily geostationary. We know that signals originating from a source moving relative to a TDRS will experience a Doppler shift [6]. It has been shown that the Doppler shift of these signals can be as much as ±50 kHz [3]. This is illustrated in Figure 2.1. The GSR normally maintains the state vector of
the satellite it is intended to communicate with and hence can simply calculate an estimate of the Doppler shift. Provided that the estimated Doppler shift is within ±3 kHz of the actual Doppler shift, the ground station can demodulate the received signal. In any system where one would forgo knowledge of the state vector of these satellites, the result would be that in general the GSR could not synchronize to the Doppler shifted carrier and thus the carrier need be estimated.

The SN currently works under a scheduling process whereby a request for service must be made in advance (prescheduling) to utilize the SN. The scheduling delay often takes as much as 21 days for the request to be processed [3]. While the request can be serviced quicker in emergencies, the delay does not allow customers to react in near real-time to emergency situations that may arise with a user spacecraft. DAMA is a proposal that seeks to provide on demand communications between a user and their spacecraft without the need for prescheduling.

2.2 NMSU’s Proposal

The initial scope of the NMSU proposal is towards implementing a “911” service where satellites that have gone into an error state may communicate this to the user when it detects such a condition. The eventual scope is to provide this service as a standard service to all DAMA capable spacecraft that require only low data rates with small data packets. Additionally it must be expanded to allow multiple access—or use by multiple users. For this thesis we assume a
single DAMA user at a time. The algorithm to be developed below is scalable to allow for multiple DAMA users at some point in the future.

The NASA GSFC proposal seeks to implement the DAMA service by maintaining the state vector information for each user spacecraft that is DAMA capable by continuously tracking each of these spacecraft. As in the MA service, with the state vector of the spacecraft known, it is routine to estimate the Doppler-shifted carrier and provide this estimate to the GSR. In contrast, NMSU's proposal gives up this state vector knowledge so that the DAMA ground station equipment is simplified. This leads to a problem with the Doppler estimation as it now must be estimated and supplied by means other than from the state vector. We propose a solution to this problem with the algorithm to be developed below that will execute on the hardware that was also developed to provide the GSR with this Doppler estimate. DAMA is to be implemented with a SS BPSK modulated communication scheme like the MA service described above. However, there are certain restrictions that determine the parameters of the scheme. The DAMA carrier is to be placed just inside the first upper TDRSS null as observed in Figure 2.2. The carrier will be placed such that a maximal Doppler shift of +50 kHz will not place the carrier too near the null so that the rolloff of the TDRSS channel and other associated GSR equipment, which bandpass filters on the mainlobe, will not adversely affect carrier estimation. The signal in Figure 2.3 consists of the MA service and the DAMA signal and demonstrates the overall response of
the TDRSS system with the addition of the DAMA signal. We furthermore see the effects of sidelobe rejection of the TDRSS system.

2.3 Spread Spectrum Fundamentals

To discuss the operational parameters of the proposed DAMA carrier estimation, it will first be necessary to provide some fundamentals of SS communication schemes and definitions of important parameters. These parameters directly affect carrier estimation performance.

We begin with a basic and widely used definition for SS systems: SS systems are distinguished by the characteristic that their signals consume a bandwidth greater than the information rate [7]. Though there are several different tech-
niques for implementing the spreading, we focus on the technique known as spread spectrum by direct sequence (DS). DS spread systems implement a scheme where the information data is acted upon by pseudo-noise (PN) data, whose elements are referred to as chips, to produce a spread spectrum bandwidth (BW). The ratio of chips to bits is typically an integer and the chip rate is often much higher than the data rate. This ratio is defined as the processing gain (PG) where

\[ PG = \frac{R_c}{R_b} \]  \hspace{1cm} (2.1)

and \( R_c \) is the chip rate in chips/s and \( R_b \) is the data rate in bits per second (bps). The PG also describes the ratio of chips/bit from which we see that each bit will be acted upon by PG chips through the use of modulo-2 addition. The PN code
sequence, $C_i$, has the property that it approximates a white noise sequence and is periodic. $C_i$ is designed purposely such that

$$C_i^T C_j = \delta(i - j)$$  \hspace{1cm} (2.2)

indicating orthogonality between PN codes of equal length but different "keys". In practice, PN codes are only approximately orthogonal. The number of 1's and 0's, with $C_i \in \{0, 1\}$, differ by at most one. Many different techniques exist for the generation of these codes and we provide the 2047 PN code as an example. Though the 2047 PN code exhibits the qualities of white noise it is in fact periodic with period 2047. This PN code may be viewed as a primitive polynomial and implemented with a shift register as seen in Figure 2.4.

In general the initial state of the shift register is a "key" and each key represents a different PN code that is orthogonal to other PN codes as described in (2.2). In this manner each PN code operates as an orthogonal basis function for each vector.
of data. Multiple users are allowed in the same bandwidth precisely because each
message is orthogonal to the other.

For the MA service, $R_c = 3$ Mchips/s. From theory it is known that the BW
consumed by this modulation scheme follows the relation:

$$BW \propto 2R_c$$

(2.3)

where $BW$ is the bandwidth, and $R_c$ is the chip or spreading rate [8]. From (2.3)
we observe that the MA service will occupy approximately 6 MHz of BW as is
illustrated in Figure 2.2 and Figure 2.3.

We will show that PG plays a large role in carrier estimation but first it is useful
to see how PG will affect the BW of a signal. As we “spread” a carrier more and
more (increase $R_c$ relative to $R_b$), the spectrum of the carrier will tend to spread
out and flatten. This can be observed in Figure 2.5 below where we have spread a
BPSK at various rates. Both PG’s in Figure 2.5 are relatively low however, it will
be shown that low PG’s are required for accurate carrier estimation. Estimation
of the carrier becomes more difficult at higher PGs since the carrier power is not
concentrated over a small band of frequencies, which would result in a sharp
Figure 2.5: Spreading Effect of Processing Gains

spectral peak, but rather distributed over a wider range. The peak in the SS case has less power and therefore noise may bury it (as intended for SS systems).

2.4 Operating Parameters Description

We now describe some of the communication parameters of the DAMA proposal. We are particularly interested in three parameters when dealing with digital communication systems: power, bit rate, and probability of bit error. For DAMA carrier estimation, we are not required to demodulate the signal and thus do not look at the probability of bit error. The first two, however, will affect our ability to perform carrier estimation.
For the purposes of this thesis, we will describe DAMA power in two different ways. The first will be SNR in $dB$ of the DAMA carrier-to-MA spectrum. We use this SNR definition when observing simulated work since the MA spectrum was modeled as AWGN. We can gain insight into this definition by observing Figure 2.3. The DAMA carrier will exhibit a peak against the passband of the MA service. Thus, we are interested in the DAMA power to that flat passband. The second way of describing power will be as the ratio $C_b/N_o$ which is used in WSC operations. This is a measure of DAMA carrier power to the noise floor. Through observations of spectra (under typical conditions) collected at WCS, the mapping between the two power ratios was seen to be approximately

$$C_b/N_o = 45dB \approx SNR = 2dB.$$ (2.4)

In this thesis, we shall use $C_b/N_o$ to describe results of actual signals and SNR when describing simulation results. To avoid confusion when comparing the two, we shall map SNR to $C_b/N_o$.

Since we intend DAMA to be a SS BPSK system, we must not only describe data rates, but also chip rates and therefore PGs. Due to the nature of the DAMA service, it has been proposed that $R_b = 1 \text{ kbps}$ [3]. The PG, as defined in (2.1), will be another parameter that is of primary concern since it determines the BW of the DAMA carrier and impacts the sampling rate. DAMA carrier estimation
accuracy will be shown to depend on PG to a large extent and therefore the chip rate will be a matter of investigation.

Sampling rate is another important parameter. It was initially proposed that the PG would be set to \( PG = 100 \) [3]. With the data rate set as above, this implies a chip rate, \( R_c = 100 \) kbps. This will exhibit a mainlobe width of 200 kHz by (2.3). From Figure 2.2 we can observe that we will need to account for another 100 kHz due to Doppler shift. The total possible BW of the DAMA carrier is then 300 kHz. We recall that to avoid aliasing while sampling the DAMA carrier, the DAMA signal must be bandlimited and be sampled at

\[
f_s \geq 600\text{kHz}. \tag{2.5}
\]

A commonly available, inexpensive 800 kHz A/D was found that matched the requirements and we thus chose \( f_s = 800 \) kHz. This has implementation ramifications that will be discussed below.

### 2.5 Carrier Estimation Problem

The problem with demodulating the DAMA carrier is the same as that for the MA carrier (though for the MA case the estimate is derived from the state vector of the satellite): the ground station is not capable of demodulating a signal if the error of the estimate is greater than \( \pm 3 \) kHz from the actual. As NMSU's proposal will not keep track of state vector information for each user spacecraft, the carrier must be estimated reliably and efficiently and then passed to the ground station.
receiver. NMSU’s DAMA proposal hinges upon accurate carrier estimation. We have developed an algorithm and hardware that performs this task and we shall describe the algorithm as well as the parameters for operation that will provide accurate carrier estimation. The hardware will provide a locking tone to the ground station receiver.

2.6 Proposed Solution

The proposed solution relies on classical spectral estimation theory with some modifications to improve performance. We begin by assuming that external analog hardware required to bandlimit and frequency shift to baseband the TDRSS and DAMA signals is available. Contained in the 400 kHz band (assuming $f_s = 800$ kHz) will be a portion of the TDRSS signal along with the entire DAMA signal.

We next employ an averaged DFT (implemented with an FFT) which, if mag-squared values are computed, is also known as a periodogram. Since we assume AWGN with zero mean, the averaging has the effect of reducing estimation error variance of the carrier based on the DFT estimate of the DAMA spectrum. We express this as

$$X(k) = \frac{1}{P} \left\{ \sum_{p=1}^{P} \left\{ \sum_{n=0}^{N-1} x[n + pN] e^{-j \frac{2\pi kn}{N}} \right\} \right\}^{2}$$

where $P$ is the number of blocks in the average, $N$ is the number of points in the block, $n$ is the sample index, and $k$ is the frequency index [9]. To obtain a frequency resolution that will enable us to estimate within the accuracy of the
GSR, we choose

\[ N = \frac{\Delta f}{f_s} = \frac{800kHz}{3kHz} \approx 267 \]  

(2.7)

but this would not allow us to use the \textit{radix-2} based FFT. We alternatively round to \( N = 512 \) for use with the FFT which yields

\[ \Delta f = \frac{f_s}{N} = \frac{800kHz}{512} = 1562.5Hz \]  

(2.8)

This increases our physical resolution beyond what is actually required.

From the result of the periodogram, we are left with an estimate of the spectrum of the received signal. We estimate the carrier frequency by choosing the maxima of the periodogram. We assume that we are operating the DAMA service such that a peak will be observed in the average. We can improve the \textit{spectrum-to-noise ratio} by utilizing a method from communication theory. It is known that the optimal solution for a receiver corrupted by AWGN is obtained by implementing a matched filter [7]. We will employ the frequency domain equivalent, spectral matched filter (SMF), which like its time domain analog is optimal and will maximize the SNR. In the time domain, a matched filter can be described by its impulse response

\[ h(t) = s(T - t) \]  

(2.9)

with

\[ 0 \leq t < T \]
where $s(t)$ is the time reversed equivalent of the received signal. The matched filter is then convolved with the received signal yielding

$$y(t) = \int_0^t s(\tau)s(T - t + \tau) d\tau.$$  \hfill (2.10)

The same approach may be applied in the frequency domain where we have a SMF that is matched to the expected, frequency-reversed Power Spectral Density (PSD) of the DAMA carrier. Through a discrete convolution between the SMF and estimated DAMA spectrum, we may arrive at a desired optimal solution that maximizes the spectrum-to-noise ratio. The SMF is described as

$$H(k) = X(N - k), \quad 0 \leq k < N$$  \hfill (2.11)

where $X(N - k)$ is the frequency-reversed equivalent of the PSD of the DAMA carrier. The SMF is then convolved with the spectrum of the received signal as

$$X_{smf} = X * H$$  \hfill (2.12)

where $*$ indicates the convolution operator. The results of applying the SMF to the process will be described in detail in section three. We then form our carrier estimate with

$$\hat{f} = \frac{\arg \max(X_{smf})}{N} f_s$$  \hfill (2.13)

where $\hat{f}$ is the estimated frequency of the carrier, $N$ is the number of points of the FFT and $f_s$ is the sampling frequency. The discrete convolution in (2.12) smears
the number of points by

\[ L_{X_{smf}} = L_H + M \] (2.14)

where \( L_{X_{smf}} \) is the translated length of \( X_{smf} \), \( L_H \) is the length of the SMF \((N = 512)\), and \( M \) is the length of the periodogram \((N = 512)\). We must subtract the maxima of the SMF, purposely located at \( N/2 \) - or 256, from the index obtained by \( \text{arg max}(X_{smf}) \). The SMF is generated in practice by generating a simulated DAMA carrier (without noise) with random data and averaging 1000 periodograms based on the simulated signal. The simulated signal is set with the PG that we wish to test. A flowchart that describes the algorithm is shown in Figure 2.6.
Figure 2.6: Flowchart for Carrier Estimation Algorithm
3 Theory and Simulation

3.1 Signal Description

We have previously stated that the DAMA carrier will use SS BPSK and we begin with a description of the communication scheme. BPSK is a communication scheme where data is encoded into the phase of a sinusoid (carrier). The general equation for $M$-ary PSK is shown in (3.1)

$$s(t) = A \cos(\omega_c t + \psi_m(t))$$

where $A$ is the amplitude of the carrier, $\omega_c$ is the carrier frequency and $\psi_m(t)$ is the phase component. In general we may add more power to the sinusoid by increasing $A$ but we assume $A = 1$ for the purposes of this thesis. $\psi_m(t)$ may take on $m$ distinct phases based upon the mapping of data to phase. For the binary case we use two distinct phases. Though we could choose any two distinct phases, in order to minimize error we typically choose the antipodal signaling as seen in Figure 3.1 as it provides the optimal decision boundary [8]. With this configuration, the phase term $\psi(t)$ may take on values corresponding to $\psi(t) \in \{0, \pi\}$. This is equivalent to modulating the sign of the sinusoid such that we may revise (3.1) to

$$s(t) = A d(t) \cos(\omega_c t)$$

where $d(t) \in \{-1, 1\}$ and is dependent on the mapping of data. As explained in Section 2.3, the data is DS spread by a PN code. For purposes of the analysis that
follows, we may look at SS BPSK as just BPSK at a higher data rate, namely the chip rate. We make this assumption since we are interested only in searching for a spectral peak of magnitude-squared data and not in demodulating the signal.

3.2 Estimation Accuracy Theory

The following arguments follow closely the work of Boaz Porat in his book, A Course in Digital Signal Processing. We have only extended his arguments to frequency estimation of a BPSK signal [4].

To begin, we make the following assumptions: $s(n)$ is a BPSK signal as described in (3.2), $S(e^{j\omega n})$ is the DTFT of $s(n)$, $w(n)$ is the rectangular windowing function, and $v(n)$ is AWGN of zero mean. The received signal would then be

$$x(n) = s(n)w(n) + v(n)w(n)$$

taking the Fourier Transform of this yields

$$X(e^{j\omega n}) = \sum_{n=0}^{N-1} s(n)w(n)e^{-j\omega n} + \sum_{n=0}^{N-1} v(n)w(n)e^{-j\omega n}$$
\begin{align*}
&= \sum_{n=0}^{N-1} s(n)e^{-jn\omega} + \sum_{n=0}^{N-1} v(n)w(n)e^{-jn\omega} \\
&= S(e^{j\omega}) + \sum_{n=0}^{N-1} v(n)w(n)e^{-jn\omega}
\end{align*}

The PSD of \( s(n) \) is given by [8]

\[ P_s(e^{j\omega}) = E \left[ S^2(e^{j\omega}) \right] = \frac{A^2}{4R} \left[ \text{sinc} \left( \frac{(\omega - \omega_c)\text{osf}}{2\pi} \right) \right]^2 \tag{3.3} \]

where we have transformed (3.3) from continuous time to discrete time, \( R \) is the data rate in bits/sec, and \( \text{osf} \) is the oversample factor in samples/bit. The maxima of the sinc function as well as the maxima of the BPSK periodogram will occur at \( \omega = \omega_c \) hence

\[ X(e^{j\omega})|_{\omega=\omega_c} = S(e^{j\omega_c}) + \sum_{n=0}^{N-1} v(n)w(n)e^{j\omega_c n} \tag{3.4} \]

and taking the magnitude-squared of both sides,

\[ |X(\omega_c)|^2 = \left( S(e^{j\omega_c}) + \sum_{n=0}^{N-1} v(n)w(n)e^{-j\omega_c n} \right) \left( S(e^{j\omega_c}) + \sum_{n=0}^{N-1} v(n)w(n)e^{-j\omega_c n} \right)^* \]

\[ = \left( S(e^{j\omega_c}) + \sum_{n=0}^{N-1} v(n)w(n)e^{-j\omega_c n} \right) \left( S(e^{j\omega_c}) + \sum_{n=0}^{N-1} v(n)w(n)e^{-j\omega_c n} \right) \]

\[ = |S(e^{j\omega_c})|^2 + 2Re \left[ S(e^{j\omega_c}) \sum_{n=0}^{N-1} v(n)w(n)e^{-j\omega_c n} \right] \]

\[ + \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} w(n)v(n)w(m)v(m)e^{-j\omega_c(n-m)} \]

Taking the expectation of the magnitude-squared value yields,

\[ E[|X(\omega_c)|^2] = E \left[ |S(e^{j\omega_c})|^2 \right] \]
The first term is by definition as provided in (3.3) and is evaluated as

\[ P_s(e^{j \omega}) = \frac{A^2}{4R} \]

The middle term evaluates to 0 since we have assumed \( E[v(n)] = 0 \). We further assume \( E[v(n)v(m)] = \gamma \delta(n - m) \), then

\[ E[|X(\omega_c)|^2] = \frac{A^2}{4R} + \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} w(n)w(m)\gamma \delta(n - m)e^{-j \omega_c(n-m)} \]

\[ = \frac{A^2}{4R} + \gamma \sum_{n=0}^{N-1} w^2(n) \]

\[ = \frac{A^2}{4R} + \gamma \nu N \]

We next define an output SNR using (3.7) as the ratio between

\[ SNR_O = \frac{\frac{A^2}{4R}}{\gamma \nu N} \quad (3.5) \]

We define the input SNR as

\[ SNR_I = \frac{\frac{A^2}{2}}{\gamma \nu} \quad (3.6) \]
where $A^2/2$ is the average power of a BPSK signal [8]. We delineate between output and input SNR to account for the application of the window function.

Finally we define a window processing gain as

$$W_g = \frac{SNR_O}{SNR_i \frac{1}{2} N}$$

$$= \frac{2}{N} \left[ \frac{A^2}{4R \gamma_N N \frac{A^2}{2}} \right]$$

$$= \frac{1}{RN^2}$$

We next employ a rule of thumb which states

$$\frac{NA^2W_g}{\gamma_N} \geq 100$$

which is given in Porat as a requirement for the reliable detection and frequency estimation of a real sinusoid in noise [4]. We modify (3.10) for the BPSK case in terms of (3.5), (3.6), and (3.9) which yields

$$\frac{A^2}{RN \gamma_N} \geq 100$$

In the development provided by Porat, the mean square error is then given as

$$E[\hat{f}_c - f_c]^2 \approx \frac{24N_o J_w}{(2\pi)^2 A^2 D^3}$$

where $N_o$ is the power density of the noise, $J_w$ is a window parameter [4], $D$ is the measurement interval ($D = NT_s$, where $T_s$ is the sampling period), and $A$ is the amplitude of the sinusoid. We further make the assumption that $E[\hat{f}_c - f_c] = 0$. 28
With this assumption and provided that (3.10) is true, the approximation in (3.12) is valid [4]. The approximation given in (3.12) can now be modified to yield

\[ E[\hat{f}_c - f_c]^2 \approx \frac{24N_\omega J_w}{\pi^2 \frac{\Delta^2}{4R} D^2} \]  

(3.13)

where we have applied (3.3) evaluated at \( \omega = \omega_c \). The result of (3.13) is an approximation of the mean square error (MSE) of the BPSK carrier frequency estimate. We note that like the sinusoid in noise case, the approximation in (3.13) is only valid when we ensure that (3.11) is true.

Equation (3.13) provides an approximation for the expected value of the MSE frequency estimate. We can use it to provide an approximation of the error in estimated frequency \( \hat{f}_c \) from a true frequency \( f_c \) from using a DFT approach to estimation. It is recognized that with the many assumptions and the inclusion of a rule of thumb that (3.13) can only give a rough approximation to the actual MSE of the frequency estimation [4].

3.3 Comparison of Theory to Simulation

Having obtained the MSE, we now show how (3.13) compares to simulation data. In the simulation we modeled a BPSK signal with a carrier frequency, \( f_c \), of 178 kHz (typical of DAMA) and the sampling frequency, \( f_s \), set to 800 kHz (as in DAMA). The simulation performed an \( N = 512 \) point DFT on the BPSK signal and measured the MSE of the estimated frequency, \( \hat{f}_c \), to the actual frequency \( f_c \). The results of the simulation are shown in Figure 3.2 where we have shown the
Figure 3.2: Comparison of Theoretical Curve Against Simulation

Simulation results versus the approximation developed in (3.13). The root mean square error (RMSE) is simply the square root of (3.13) and it is the expected value in Hz that $\hat{f}_c$ is from $f_c$ as a function of SNR. This relates directly to the accuracy of estimating $f_c$ with $\hat{f}_c$ to within the GSR tolerance and provides a means by which we can approximately determine the accuracy for a given SNR.

We can conclude from the simulation that at high SNR's ($< 5$ dB), the theoretical curve and the simulation curve match, while at low SNR's the theoretical curve becomes invalid (due to assumptions made during calculation) [4]. We further conclude that at high SNR's (3.13) will provide a good estimate of the mean of the estimation accuracy and allow us to predict performance. At low
SNR's the simulation curve approaches a condition where the noise is dominating the spectrum and the maximum peak is uniformly distributed over the 400 kHz band, yielding near random estimates. The theoretical curve is asymptotic to zero RMSE whereas the simulation curve will actually converge only to the difference between the true frequency and the selected DFT frequency—the difference is unlikely to be zero. This illustrates an important point regarding accuracy of carrier estimation: since we quantize to the DFT frequency points, there will most likely be an error irrespective of what SNR we are operating at. The maximum amount of this error assuming large SNR is given by

$$\max(f_c - \hat{f}_c) < \frac{f_s}{N}$$

This error can only be reduced by increasing $N$, the number of points of the DFT.

### 3.4 Simulation Model Description

Though we have developed a theoretical analysis culminating in (3.13), the approximation is not tight enough to provide proof of concept. We turn to a Matlab simulation model to provide a core proof of concept. We shall use this simulation model to explore the operational parameters of the algorithm. The simulation models the DAMA carrier against other MA users and AWGN. The simulation builds up a SS BPSK digital waveform based on the PG that we wish to test and then adds appropriate AWGN. It then estimates the doppler-shifted carrier frequency based upon the algorithm developed in section two. A record is
kept of carrier frequency estimations and those that fall within the tolerance of
the ground station at WSC are counted as an accurate estimation. Likewise any
estimation that is outside of the ground station tolerance is considered inaccurate.
By performing the simulation 10,000 times for each SNR and desired PG, we
obtain a plot that describes estimation accuracy.

The simulation was originally written without the SMF and then rewritten to
include the SMF process. The SMF improves estimation accuracy and allows for
higher PG’s. The Matlab code for the simulation is given in Appendix A.

3.5 Simulation Results

We now provide results of simulation both in the SMF and non-SMF cases.
The simulation results for the non-SMF are shown in Figure 3.3 and illustrate
estimation accuracy as a ratio of accurate estimations to total estimations versus
SNR. In Figure 3.3, we plot three curves for PG = 10, 20, and 100. The curves
are generated through 10000 estimates per SNR and we perform 8 DFT blocks of
N = 512 points. At an SNR = 2 dB, the results of Figure 3.3 demonstrate that
estimation accuracy would be approximately 14%, 60%, and 88% for PG = 10, 20,
and 100 respectively. NASA has placed the requirement that any implementation
should have as high a PG as possible. From Figure 3.3 it is clear that only the PG = 10 case is practical.

Carrier frequency estimation may also be observed through the use of histograms which also relate information regarding the variance of the estimations. In Figure 3.4, Figure 3.5, and Figure 3.6 we show histograms for PG = 10, 20, and 100 respectively. Each is shown for SNR = 2. In each figure the actual carrier frequency is denoted by the center dashed line while the GSR tolerance (±3 kHz) is shown by the outer dashed lines.

The results with the SMF enhancement, as described in section two, are much better (Figure 3.7). The results shown in Figure 3.7 are generated as in the
Figure 3.4: Non-SMF Frequency Estimation for PG = 10, SNR = 2 dB

Figure 3.5: Non-SMF Frequency Estimation for PG = 20, SNR = 2 dB
Figure 3.6: Non-SMF Frequency Estimation for PG = 100, SNR = 2 dB

Figure 3.7: Family of Curves for SMF Case
Figure 3.8: SMF Frequency Estimation for PG = 10, SNR = 2 dB

non-SMF case with the exception that we have now included SMF processing. In Figure 3.7, we show estimation accuracy curves for PG = 10, 40, and 100. Here we see that estimation accuracy of the $PG = 100$ case has improved seven-fold. The case of $PG = 40$, a likely DAMA operating parameter, demonstrates accuracy at nearly 90% in a typical operating SNR region. As in the non-SMF case, we observe the histograms of Figure 3.8, Figure 3.9, and Figure 3.10 which are shown for PG = 10, 40, and 100 respectively. Each figure is shown at SNR = 2. From these figures it is clear that there is less variance and therefore more estimations within the GSR tolerance.
Figure 3.9: SMF Frequency Estimation for PG = 40, SNR = 2 dB

Figure 3.10: SMF Frequency Estimation for PG = 100, SNR = 2 dB
3.6 Theoretical/Simulation Data Summary

We have demonstrated results for a model that attempts to simulate DAMA carrier estimation in the presence of the TDRSS spectrum which is modeled with AWGN. We provide results indicating that accurate carrier estimation is possible with the algorithm developed in section two. Additionally, we have determined some operating points for the PG parameter. We have shown that we can accurately estimate the DAMA carrier 90% of the time with a $PG = 40$ at the typical SNR range. The simulation has provided a demonstration and we offer a loose theoretical approximation (3.13) to the estimation accuracy. In section four, we shall use data collected at NASA’s White Sands Complex (WSC) to further validate the simulation results.

Appendix A includes all of the developed code for the simulation model including instructions for its use. Additional code is provided to perform data visualization.
4 WSC Data Collection Experiment

4.1 Motivation of WSC Data Collection Experiment

An experiment was devised to perform validation of the simulation model by collecting actual signals transmitted through TDRSS and collected at WSC. We subsequently processed them offline using the estimation algorithm. The fundamental idea of this experiment is that we can observe the performance of the algorithm with actual DAMA signals. If the algorithm using actual signal data performs similar to the simulation under various PGs and at various SNRs, we may state with a degree of certainty that the simulation model is indeed accurate enough to predict carrier estimation. This also allows for the prediction of the performance of the algorithm if any of the operating parameters need to be changed. A side benefit is that we may also perform in-house testing using simulated signals without the expense of interrupting critical TDRSS operations for testing.

This section discusses the actual experiment performed at WSC, including details regarding setup, the processing of the data, and the conclusions drawn. We verify the simulation model's results with actual TDRSS data. Additionally, the experiment points out the realistic operating boundaries which are an important part of the DAMA design.
4.2 Data Collection Setup

Two sets of equipment were used to collect test signals that were sent from the ground station and relayed off of a TDRS back to the ground station. The setup was as shown in Figure 4.1. The Transmit (Tx) equipment consisted of a computer equipped with a high speed PDMA32 Data Transfer Card (PDMA32). The purpose of the Tx equipment was to send a data vector to ground station equipment where it was BPSK modulated and transmitted to a TDRS. The data vector sent consisted of underlying data bits of \{±1\} with \(R_b = 1\) kbps which was then spread by a spreading vector at a rate of \(R_c = PG \cdot R_b\) chips/s. Several of these data vectors, consisting of raw binary data and DS spread with a PN code (see section two), were generated in advance of the experiment and then used as a data source. The source code (wsands.m, wsands2.m, wsands3.m, and wsands4.m) is given in Appendix A.
The Receive (Rx) equipment consisted mainly of a LeCroy Digital Storage Oscilloscope (DSO) to capture IF signals and another computer to store captured signals. As the TDRSS channel is bandlimited to approximately 40 MHz, the DSO was set to sample at a rate of 100 MHz. This was the closest value to the Nyquist rate that the DSO was capable of sampling at. The DSO was capable of storing the captured data waveforms with either 50,000 samples or 100,000 samples depending on the storage medium that was used and both sizes were collected.

With the hardware setup described, we now turn our attention to the test set. The test set was established to test a variety of key parameters and determine the operational bounds of each. The key parameters are

- Processing Gain

- DAMA Carrier power-to-noise ratio ($C_b/N_o$)

- Placement of IF Carrier Frequency against TDRSS spectrum

The PG, defined in (2.1), is the most critical of the three. Initial work with the PG indicated a PG of 100 could be used [3]. Subsequent simulations indicated that at this PG value the estimation accuracy was not reliable and lower values were investigated (see section three). It was included in the test set for completeness. PG's of 10, 20, 40, and 100 chips per bit were the focus of the test set.
Three different carrier power-to-noise ratios were investigated. These ratios were 40, 45, 50 dB. These values were chosen as typical values based upon the experience of WSC staff [10]. It should be noted again that these values are described as a ratio of the carrier power to the noise floor in dB and not carrier power to MA spectrum as described in section three.

The last test parameter is that of the carrier placement. The carrier frequencies were chosen such that a range of frequencies near the TDRSS null could be examined. Recall from section two that we intend to place the DAMA carrier at 2.29 GHz which at IF is 2.9 MHz above the TDRSS center frequency. The range of test frequencies are observed in Figure 4.2. By examining a range of IF frequencies, we are allowed to effectively simulate a Doppler shift as well as examine the effects of the rolloff of the TDRSS channel. Comparing this to the TDRSS spectrum shown in Figure 2.2, we see that the upper range will be affected by the TDRSS rolloff. The full test set is shown in Table 1. The full test set had to be reduced for logistical reasons to lessen impact on TDRSS operations, however, the reduced test set provides enough insight for simulation verification.
Table 1: Test Sets Captured

<table>
<thead>
<tr>
<th>PG</th>
<th>( F_c \text{ MHz} )</th>
<th>40 dB</th>
<th>45 dB</th>
<th>50 dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>32.60</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>32.65</td>
<td>*</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>32.70</td>
<td>*</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>32.80</td>
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<td>20</td>
<td>32.60</td>
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<td></td>
<td>32.65</td>
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<td>32.70</td>
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<td>*</td>
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<td></td>
<td>32.80</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>32.60</td>
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<td></td>
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<tr>
<td></td>
<td>32.65</td>
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<tr>
<td></td>
<td>32.80</td>
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</tr>
</tbody>
</table>

* indicates data collected

4.3 WSC Collected Data Processing

We noted above that the captured waveforms were sampled at 100 MHz and stored as either 50,000 or 100,000 length vectors. In section two it was also noted that the bandwidth of the DAMA carrier plus maximum possible Doppler shift yielded a 300 kHz frequency search space and that the FFT resolution will be 1562.5 Hz. Downsampling the captured waveforms to \( f_s = 800 \text{ kHz} \) was impractical due to the problems of designing a narrow band decimation filter sharp enough for the rate conversion. Instead we seek a solution that will allow us to perform a frequency search with a nearly equivalent FFT resolution. We see then that

\[
\Delta f_{\text{experiment}} = \frac{f_s}{N} = \frac{100 \text{MHz}}{65536} = 1525.8 \text{Hz}
\]  

(4.1)

provides a nearly equivalent FFT resolution to (2.8). In order to provide the
resolution in (4.1) and maximize the use of the short data sets, the vectors were either overlapped in the 100,000 sample case or zero-padded in the 50,000 length case. Without zero-padding the 50,000 length vector to 65536, the DFT does not meet the required resolution. The net result of this operation is a collection of 65536 length vectors with which to work with. These vectors were then used in a periodogram of eight data blocks chosen at random and processed with the simulation code that was used with a synthetic waveform (see Appendix A). This process was iterated 500 times, due to maximum data support, to form simulation bounds using WSC data.

4.4 WSC Data Results Compared to Simulation

The results of the processed data in comparison to simulation results are shown in Figure 4.3 below. The plot shown is for \( PG = 10 \) with the simulation represented by the curve and the individual data points being the collected data across the various frequencies indicated. The plot indicates successful carrier estimation to within ±3 kHz as the ratio of accurate estimates to total estimates versus \( C_b/N_0 \). We can make several observations from the plot.

The first observation we can make is in regards to carrier power \( C_b/N_0 \). We observe that at a \( C_b/N_0 = 40 \) dB, the estimation accuracy is much less than the simulation exhibits indicating a practical limit to \( C_b/N_0 \). As \( C_b/N_0 \) increases to 45 and 50 \( C_b/N_0 \), estimates performed with actual WSC signal data match
those using synthetic data. This result indicates that we can estimate Doppler accurately provided that the carrier power is high enough for the range of carrier frequencies specified in Figure 4.2. This is an intuitive result as well since we would fully expect that a carrier with higher power will exhibit a more defined peak against the TDRSS spectrum. We also observe that the nominal carrier power provided by WSC will be sufficient as an operational bound. Previous work indicated that the DAMA carrier power and the MA carrier power can be relatively the same [3]. For the algorithm developed however we must have enough power so that the DAMA carrier exhibits a peak against the MA spectrum. Based
on collected data for the $C_b/N_0 = 40$ case, the DAMA carrier is lost in the MA spectrum and in general cannot meet reliability requirements.

4.5 Conclusions of WSC Data Collection

We have shown some important results with the WSC Data Collection analysis. The algorithm using actual TDRSS signals performs nearly the same as when using synthesized signals (see Figure 4.4). Therefore the synthesis of modeled signals is accurate to actual TDRSS signals. We rely heavily on the simulation to provide proof of concept and so the justification of the simulation is vital: the simulation is used to narrow in on the operating parameters that we should like to run at. Though we only have significant data for the $PG = 10$ case, we extend the results described above to higher $PG$'s with the assumption that the effects of spreading the signal even further in the frequency domain will cause negligible disparities between the simulation and actual operation. We can use simulated waveforms to implement additional, and important, real-time hardware tests.

There remains one outstanding issue with regards to accurate carrier estimation. We have seen previously that the TDRSS channel begins to rolloff sharply near the location that we would like to place the DAMA carrier. Though the data did not support the investigation—at least in the spectral matched filter case—it is nevertheless true that if the DAMA carrier is nominally placed too close to the
null, then the rolloff will adversely affect accuracy. We must also avoid placing the DAMA carrier in the MA passband.

Overall the successful comparison of captured data to simulation data indicates that provided the DAMA carrier has sufficient power, we can explore additional operation bounds with a high degree of confidence.
5 Carrier Estimation Hardware and Software

5.1 Motorola DSP56303EVM Description

The \textit{DSP56303EVM} (EVM) is the core hardware component of the carrier estimation hardware developed. It executes the DSP specific real-time assembly language version of the carrier estimation algorithm (see Appendix B). The EVM is an evaluation module which is designed to be used in prototyping applications. As such, it offers a variety of interface options and configuration settings that make it adaptable to many different types of development projects. The board contains a DSP56303 24-bit digital signal processor that executes the assembly code routines. It also features a DSP56002 specifically for use in I/O functions through a JTAG/OnCE port. JTAG is a protocol that was developed to allow hardware and software developers to observe and manipulate hardware for troubleshooting purposes. The JTAG port for the EVM is primarily used with a PC and debugger software that allows a developer to load code into the EVM, single step through sections of code, and observe the contents of memory and registers. The onboard DSP56002 is not available for coprocessing code, but rather is used to control the I/O functions to the host PC. The EVM also contains 32K x 24-bit Fast Static Ram (SRAM) built with three banks of 32k x 8 bit SRAMS with 15 ns access times. An additional 64k x 8 bit Flash Programmable Erasable Read-Only Memory (PEROM) is provided for stand alone operation. The EVM also contains
a 16 bit CODEC for sampling incoming analog waveforms and producing analog waveforms out from digital data [11].

The EVM is based upon the DSP56300 core which is shown in Figure 5.1. The EVM specifically uses the DSP56303 processor. The processor is capable of 80 MIPS with an 80 MHz clock. It provides for backwards compatibility with 56k core code so that code written for earlier processors should function equally well on the newer cores. Due to a seven level instruction pipeline architecture, the DSP56303 is capable of effectively an instruction every clock cycle. It is based on the Harvard architecture so that it works with a dual memory structure. This architecture is particularly suited for parallel move instructions. This allows the
programmer to access two different memory structures at a time. For more on the DSP56303 please see [12].

The DSP56303 not only provides the processing power required to perform carrier estimation efficiently, but it is highly configurable and can interface to a large number of peripheral products. Though higher level languages (C) may be used to program the processor, it is most efficient when programmed in assembly. The assembly language that the DSP56303 uses is specialized to perform DSP tasks and includes features for that purpose. The Real-Time version of the carrier estimation algorithm is developed completely in assembly (see Appendix B).

To create a program for the DSP56303, code is written in assembly language, and then assembled through the use of Motorola software tools to machine usable object code (.cld files). We may then use a software tool like Domain Technologies Debug-EVM to load the code into program memory of the DSP56303. With the Debugger software, we can utilize the JTAG port to single step through code and observe the results on calculations.

For the DAMA project, as was described in section two, we are required to sample at a higher rate than the EVM can perform with the on board CODEC. We will use the on board CODEC in the generation of the locking tone to the ground station receiver. To sample the DAMA spectrum, we need to interface a high speed A/D.
5.2 Burr Brown 800kHz A/D

Earlier we noted we must search over a 300 kHz BW (200 kHz for the DAMA mainlobe, assuming no more than a $PG = 100$, and with $\pm 50$ kHz for maximum Doppler shift) which was revised from an earlier estimate of 364 kHz. The Burr Brown 12 bit 800 kHz ADS7810/19 (BB A/D) was chosen since it has a sampling frequency of 800 kHz which gives a Nyquist interval of 400 kHz and because it is available in a convenient evaluation package for easy interfacing to the DSP56303EVM. The 12-bit samples of the BB A/D have a dynamic range of -72 dB which is sufficient for the TDRSS system. It was necessary to build an interface board to allow samples collected with the BB A/D to be passed to the 303.

5.3 A/D Interface Board

The A/D Interface Board (ADIB) was developed as a Masters project by Tim Baggett [13]. Its purpose is to provide an interface to allow the EVM to communicate with the BB A/D. The board was developed to allow samples taken with the BB A/D to be passed into a peripheral (upper) memory location, which corresponds to the memory mapped I/O portion of memory. Though it is not a requirement, we may access the data samples with an efficient fast interrupt routine which is preferable. It is also possible with the interface board to use direct memory transfers (DMA) though this was not implemented in the Real-Time ver-
sion of the carrier estimation algorithm. The board allows for user configuration of the specific memory location the samples will be written into. The ADIB was further complicated by voltage level discrepancies between the BB A/D and the 303. This was overcome through the use of zero wait-state level translators that adjust the output levels of the BB A/D to levels acceptable by the 303.

5.4 Additional Hardware

In an actual implementation of the DAMA carrier estimation hardware, there will be additional hardware required. Recall from the discussion of the DAMA project implementation, it was stated that WSC could provide the DAMA carrier at an IF of 32.65 MHz. The range of frequency values that a DAMA carrier can take, identified as 300 kHz, must be pre-filtered to bandlimit the signal containing the DAMA carrier from the MA waveform or aliasing will result. This is to be accomplished using an analog pre-filter set to a passband over the range of interest.

With the signal now appropriately pre-filtered, the signal must be frequency shifted to baseband utilizing additional commonly available analog hardware. With this pre-processing accomplished, the DAMA carrier can be sampled and the digital signal processed to detect and estimate the carrier frequency utilizing the algorithm described in section two. Upon the algorithm’s determination of the DAMA carrier frequency, the CODEC on the EVM is utilized to provide a locking tone. By choosing a sample rate of 32 kHz for the synthesis of the locking tone, we
need only frequency multiply by 25 to get the appropriate frequency value (< 400 kHz). Afterward we frequency shift this tone back to IF for the GSR. This is illustrated in Figure 5.2. The analog hardware required to implement the frequency multiplication and shifting is commonly available and an essential component in implementation.

5.5 Software Description for Real-Time Carrier Estimation

The carrier estimation code is designed to work with the EVM and the ADIB to sample the incoming signal, process the signal, and then produce a locking tone to the ground station. The core of the program is based upon the code supplied with the EVM named pass.asm. The purpose of the pass.asm is to initialize the EVM (CODEC and processor), then transfer samples to/from the CODEC from/to the processor. All signal processing is performed between transfers. This code is important because in most cases of programming a Motorola DSP56xEVJ, the algorithm to be implemented will use pass.asm as the starting point. The carrier estimation code is slightly modified in that while it uses pass.asm as the core, it must set the EVM to properly receive samples from the BB A/D
and instead of reading sample values from the on-board CODEC, it will instead read sample values from an upper memory location as described above. Upon completing the initialization of the EVM (CODEC and processor) to work with the BB A/D, the carrier estimation algorithm begins. We begin by looking at the flowchart in Figure 2.6 which describes the algorithm.

The initial step from the reset condition is to initialize memory and on-board CODEC and prepare the EVM for communication with the ADIB. The algorithm then begins by filling the sample buffer with values. Once it has achieved a full block of 512 samples, it applies a windowing function of the user's choice. Typically either Rectangular or Hamming window coefficients are used. Included in this window function is an iteration scaling factor of $1/P$, where $P$ is the block number, which is nominally set to 0.125. This is included to scale for averaging. This has the added advantage of saving computation time since both windowing and average scaling are accomplished at once.

From the flowchart we now see that the actual FFT is performed. The FFT routine is supplied by Motorola (see Appendix B) and produces a normally ordered Fourier transform, as opposed to a bit-reversed, complex result from a normally ordered input. The result is stored such that the real component of the result is in $X$ memory and the imaginary in $Y$ memory. We compute the magnitude-squared of the FFT and repeat this step averaging magnitude-squared data $P = 8$ times to form the periodogram. If we assume that $x(n) \in \mathbb{R}$ where $x(n)$
is the received, sampled signal, we need only search the first $N/2$ points due to Hermitian symmetry

$$X(k) = X^*(N - k), \quad 0 \leq k \leq N - 1. \quad (5.1)$$

This reduces the computational time and memory usage.

Continuing with the flowchart in Figure 2.6, once the periodogram is computed, we convolve the result with the SMF and begin a search for the maxima of the enhanced spectrum. The result of this search is an index corresponding to the dominant spectral component. From this index a frequency may be found according to the relation

$$\hat{f} = \frac{k - \frac{L}{2}}{N} f_s \quad (5.2)$$

where $\hat{f}$ is the estimated frequency [14], $k$ is the index found from the search, $L = N$ is the length of the SMF, $N$ is the number of points of the FFT, and $f_s$ is the sampling frequency. A sine wave table is then used to provide a locking tone at $1/25$ frequency that the ground station expects. As described above, this locking tone will be frequency multiplied up IF. The DSP56303 assembly code is given in Appendix B.
6 Conclusions and Future Work

In this thesis we have described an algorithm to perform carrier estimation for the DAMA project. We have shown that the estimation accuracy depends primarily on the processing gain of the SS BPSK signal though some tertiary parameters also affect accuracy. We have developed a simulation model that provides proof of concept and provides DAMA operational parameters. Through the use of data collected at the WSC, we have verified the simulation model and established an operational point of PG = 40 with a corresponding accuracy of 90%.

In addition to the development above, we have developed Real-Time code based on the algorithm developed utilizing a Motorola DSP56303EVM. The entire project is implemented in hardware and functions equivalently to the simulation model.

Future work might involve the formulation of a tighter theoretical bound as well the development of the analog hardware required for implementation. This work could be applied in other applications relating to communications between user spacecraft and commercial telecommunication satellites. In this scheme, additional carrier pre-shifting would be required.
A Matlab Simulation Code
dama.m

001 %roofULL&v risk o&thm of I#t&men of a DAMA
002 %
003 % Description: This function allows simulation of the estimation of a DAMA
004 % user's Doppler-shifted carrier frequency. We assume a spread spectrum
005 % system and the presence of other SS systems (modeled by AWGN).
006 %
007 % Programmer: Phillip De Leon
008 %
009 % Creation Date: December 31, 1995
010 % Last Revision: Sept. 24, 1998
011 %
012 %
013 % Version History:
014 % 1.0  - frequency estimate of sinusoid in noise
015 % 2.0  - frequency estimate of DAMA carrier in noise (spread spectrum)
016 % 3.0  - better memory management, more efficient
017 % 4.0  - STFTs or average FFTs or MA filter smoothing of FFT bins
018 % 5.0  - 800KHz sampling rate, 512-point FFT
019 % 6.0  - frequency estimate now over 512 blocks (of a longer signal).
020 % 7.0  - added frequency-domain matched filter to search
021 %
022 % Required subroutines: Use PLOT_DAHA_DATA.M to visualize data
023 %
024 % Notes:
025 % 1) For n
026 % SNR = 027 % For n
028 % MA users DAMA-to-MA power ratio is
029 %
030 % 2) This code is compute intensive!!!
031 %
032 % References: Digital and Analog Communication Systems by Couch p.359
033 %
034 % Copyright (c) 1998 by Phillip De Leon, All Rights Reserved
035 %
036 %
037 clear;
038 %
039 %
040 % DAMA User's Parameters
041 %
042 % Fc_DAMA = 164e3; % DAMA user's carrier frequency (after shifting) in Hz
043 %
044 % max_Doppler = 64e3; % maximum Doppler shift of +/-64kHz
045 % est_tolerance = 3e3; % must estimate carrier to within +/- est_tolerance
046 %
047 % Communication System Parameters
048 %
049 % Fs = 800000; % output signal sampling freq. (samples/s)
050 %
051 %
052 %
053 %
054 % Rb_DAMA = 1000; % data rate for DAMA (bits/s) Fs/Rb_DAMA must be integer
055 %
056 %
057 %
058 %

57
069 \text{Rc}_{MA} = 3000000; \quad \% \text{chip rate for MA (chips/s) 3000K}
070
071 \% \text{Frequency Estimation Parameters}
072 \% \text{Estimation of } F_c \text{ occurs over a bandwidth of...}
073 \% F_c = \text{max}\_\text{Doppler} - \text{main\_lobe\_BW}/2 < F_{\text{DAMA}} < F_c + \text{max}\_\text{Doppler} + \text{main\_lobe\_BW}/2
074 \% 0 < f < 328
075 \% N = 512; \quad \% \text{length data block to take FFT over}
076 \% window = 0; \quad \% \text{if 0 assume rectangular window, 1 Hamming Window}
077 \% if (window)
078 \quad \text{w} = \text{hamming}(N); \quad \% \text{Hamming window used in FFT}
079 \% end;
080
081 \% \text{Simulation Parameters}
082 \% \text{number of estimates} = 30; \quad \% \text{number of frequency estimates to perform}
083 \% \text{for each SNR typically 10000}
084 \% \text{num\_FFTs} = 8; \quad \% \text{average 8 FFTs per estimate;}
085 \% \text{snr} = [-6]; \quad \% \text{vector of SNRs (in dB) to simulate typically from -2.2 to 4.7dB}
086
087 \quad \text{for} \ m = 1:\text{length(snr)}; \quad \% \text{m is index for SNRs}
088 \quad \text{disp(sprintf('••• SNR Xd •••',snr(m)));
089 \quad \text{max\_pos\_est\_error} = 0; \quad \% \text{reset variables}
090 \quad \text{max\_neg\_est\_error} = 0;
091 \quad \text{rand('seed',0); \quad \% \text{reset uniform generator seed}
092 \quad \text{randn('seed',0); \quad \% \text{reset normal generator seed}
093 \% \text{for} \ n = 1:\text{number\_of\_estimates}; \quad \% \text{n is index for estimate #}
094 \quad \% \text{mm}
095 \quad \text{sum\_mag\_X\_sqrd} = \text{zeros}(N/2,1); \quad \% \text{malloc storage for accumulation of FFT data}
096 \quad \text{sum\_mag\_S\_sqrd} = \text{zeros}(N/2,1); \quad \% \text{malloc storage for accumulation of FFT data}
097 \% \text{-------------}
098 \% \text{Synthesize SS signal}
099 \% \text{-------------}
100 \% \text{Generate digital message}
101 \quad \text{data} = \text{randcell(num\_FFTs*N/samples\_per\_bit),1}); \quad \% \text{generate data (bits) to modulate}
102 \% \text{-------------}
103 \% \text{Digital BPSK Modulation}
104 \quad \text{start} = 0;
105 \quad \text{stop} = \text{samples\_per\_bit} - 1;
106 \quad \text{msg} = [\ ];
107 \% \text{for} \ i = 1:\text{length(data)}
108 \quad \text{n} = [\text{start}:\text{stop}];
109 \% \text{if} ('data(i)') \% \text{if 0 multiply by -1}
110 \quad \text{msg} = [\text{msg'}(-1)*\text{sin}(2*\text{pi}*\text{Fc}/\text{Fs})']; \quad \% \text{build up message signal}
111 \quad \text{else}
112 \quad \text{msg} = [\text{msg'}*\text{sin}(2*\text{pi}*\text{Fc}/\text{Fs})']; \quad \% \text{build up message signal}
113 \quad \text{end;}
114 \quad \text{start} = \text{stop} + 1;
115 \quad \text{stop} = \text{min}(\text{start} + \text{samples\_per\_bit} - 1),\text{num\_FFTs*N});
116 \quad \text{end;}
117
118 \% \text{Direct Sequence Spreading}
119 \quad \text{PN\_code} = \text{round(randcell(num\_FFTs*N/samples\_per\_chip),1));
120
58
```matlab
start = 1;
stop = samples_per_chip;
s = [];
for i = 1:length(PN_code)
    n = [start:stop];
    if ('PN_code(i)') % if 0 multiply by -1
        s = [s' (-1)*mag(n)']'; % build up spread signal
    elseif % if 1 multiply by 1
        s = [s' mag(n)']'; % build up spread signal
    end;
    start = stop + 1;
end;
stop = min((start + samples_per_chip - 1),num_FFTs*N);

% Compute FFT of BPSK-SS for Matched Filter Use
S = fft(s(1:N));
mag_S_sqrd = real(S(1:N/2).*conj(S(1:N/2)));
sum_mag_S_sqrd = sum_mag_S_sqrd + mag_S_sqrd;
avg_mag_S_sqrd = sum_mag_S_sqrd/num_FFTs;
MF = flipud(avg_mag_S_sqrd);
for k = 1:num_FFTs; % k is index on FFT number
    % Add AWGN noise (MA users + channel noise) according to desired SNR to SS signal
    noise = randn(N,1).*sqrt(cov(s)/(10^nr/(snr(m)/10))); % ./ ?
    s_prime = s(1+N•(k-1):N•(k-1)+512); % Take length N buffer of samples from total.
    r = s_prime + noise; % carrier + noise
    r = r ./ sqrt(cov(r)); % scale to unit variance
    x = r;
    % Window signal
    % ---------------
    if ('window')
        x = r; % no window => rectangular window
    else
        x = w .* r; % window with preset window
    end;
    X = fft(x);
    mag_X_sqrd = real(X(1:N/2).*conj(X(1:N/2))); % due to symmetry need only scan lower half
    sum_mag_X_sqrd = sum_mag_X_sqrd + mag_X_sqrd;
end; % FFT loop

% Frequency estimation
% ---------------------
avg_mag_X_sqrd = sum_mag_X_sqrd/num_FFTs;

% Frequency-Domain Matched Filtering
MF_mag_X = conv(MF,avg_mag_X_sqrd);

if (0)
    k = find(avg_mag_X_sqrd == max(avg_mag_X_sqrd));
    if (length(k) > 1)
        k = median(k); % choose the median k if there are several
    else
        k = k;
    end;
end;
end;
end;
end;
end;
end;
```
if (length(k) > 1)  
k = median(k);  % choose the median k if there are several
else
  k = k;
end;

k = k - N/2 - 1;  % MF spreads range by 2

est_data(m,k) = est_data(m,k) + 1;  % tally estimate

end;  % estimates loop

save dama_data est_data

end;  % snr loop

% -----------------------------
% Save Data in MATLAB 4.x format
% -----------------------------

x = version;
if (x(1)==53)  % running on MATLAB 5.x
  save -v4 dama_data Rc_DAMA Fs Fe snr est_tolerance N window number_of_estimates est_data
else  % running on MATLAB 4.x
  save dama_data Rc_DAMA Fs Fe snr est_tolerance N window number_of_estimates est_data avg_mag_X_sqrd
end;
mf_bpsk_ss.m

001 %******************************************************************************
002 % MF_BPSK
003 %
004 % Description: This function computes the matched filter for the PSD of the
005 % BPSK-SS frequency-domain waveform. The matched filter coefficients are
006 % stored in a file for use in the DAMA.M code. We may be able to use the
007 % theoretical PSD.
008 %
009 % Programmer: Phillip De Leon
010 %
011 % Creation Date: Sept. 25, 1998
012 % Last Revision: Oct. 24, 1998
013 %
014 % Version History:
015 % 1.0 - MF for the BPSK-SS
016 % 1.1 - New Vectorization Methods - will reduce run time.
017 % 1.2 - Added Crash Recovery - ALL data is saved to temp.mat prior to
018 % next major algorithm step.
019 %
020 % Required subroutines:
021 %
022 % Notes:
023 % 1) N must be the same as in DAMA.M
024 %
025 % Approximate Runtime:
026 % P200 win98 : ~22 minutes
027 % Mac : Not performed
028 % Pxx Linux : Not performed
029 %
030 % References:
031 %
032 % Copyright (c) 1998 by Phillip De Leon, All Rights Reserved
033 %******************************************************************************
034 ON = 1; % Used to turn options on or off.
035 OFF = 0;
036 ERR = 0; % Set ERR to level achieved before crash - results
037 % are saved in temp.mat
038 if ERR == 0 disp('Operation Level One:')
039 % ----------------------
040 % Code Parameters
041 % ----------------------
042 spreading_opt = ON; % ON to spread - OFF to just BPSK modulate.
043 window = OFF; % if OFF assume rectangular window, ON Hamming Window
045
046 % ----------------------
047 % DAMA User's Parameters
048 % ----------------------
049 Fc_DAMA = 200e3; % DAMA user's carrier frequency (after shifting) in Hz
050 % Set to middle of DAMA frequency range.
051
052 % ----------------------
053 % Communication System Parameters
054 % ----------------------
055 Fs = 800000; % output signal sampling freq. (samples/s)
056 Fc = Fc_DAMA; % assume unshifted DAMA carrier
057
058 Rb_DAMA = 1000; % data rate for DAMA (bits/s) Fs/Rb_DAMA must be integer
059 Rc_DAMA = 50000; % chip rate for DAMA (chips/s) 100K?
060 if rem(Fs,Rb_DAMA) ~= 0
% samples_per_bit MUST be an integer!!
end
if rem(Fs, Rc_DAMA) ~= 0
 error('samples_per_chip MUST be an integer!!')
end
samples_per_bit = Fs/Rb_DAMA; % must be integer
samples_per_chip = Fs/Rc_DAMA; % must be integer

-------------------------------
Frequency Estimation Parameters
-------------------------------
Estimation of Fc occurs over a bandwidth of...
Fc = max_Doppler - main_lobe_BW/2 < F_DAMA < Fc + max_Doppler + main_lobe_BW/2
% 0 <= f <= 328
N = 512; % length data block to take FFT over

if (window)
w = hamming(N); % Hamming window used in FFT
else
w = ones(N,1);
end

---------------------
Averaging Parameters
---------------------
num_FFTs = 5000; % Average iterations - higher -> better resolution
save temp % End of level One - save work so far to temp.
end

if ERR ~= 1 | ERR ~= 0 % Check Error Level.
disp('Operation Level Two:')
% Generate digital message
M = num_FFTs*N*Rb_DAMA/Fs; % number of bits to take PSD over
save temp % End of level Two - save work so far to temp.
end

if ERR == 1 | ERR == 0 % Check Error Level.
disp('Operation Level Three:')
% Spread BPSK Signal
msg = sin(2*pi*(0:M*samples_per_bit-1)*Fc/Fs); % BIG vector - not for the weak!!
msg = msg'; data =
filter(ones(samples_per_bit,1),1,upsamp((-1).-'(round(rand(M,1))),samples_per_bit));
% Previous line generates a data vector with each
% bit represented by samples_per_bit number of
% samples.
msg = msg.*data; % data vector is multiplied by the signal vector
% to generate the message vector - BPSK modulated.
save temp % End of Level Two - save work so far to temp.
end

if ERR == 2 | ERR == 1 | ERR == 0; disp('Operation Level Three:')
% Spread BPSK Signal

% done with error checking

% start with frequency estimation
% and averaging
% if (window)
i = length(data)
else
w = hamming(N); % Hamming window used in FFT
end

% calculate samples_per_bit
samples_per_bit = Fs/Rb_DAMA;

% calculate samples_per_chip
samples_per_chip = Fs/Rc_DAMA;
if spreading_opt % If spreading option is on then spread signal.
PN_code = filter(ones(samples_per_chip,1),1,...
upsamp((-1).^round(rand(cell(num_FFTs*N/samples_per_chip),1))..., samples_per_chip));
s = mag.*PN_code; % s is the BPSK modulated spread spectrum signal.
end

% Compute FFT of BPSK-SS for Matched Filter Use from averages.
% h = waitbar2(0,'Generating Matched Filter Frequency Response...');
start = 1;
stop = N;
save temp % End of Level Three - save work so far to temp.
end

if ERR == 3 | ERR == 2 | ERR == 1 | ERR == 0
disp('Operation Level Four:')
end

sum_mag_S_sqrd = zeros(N/2,1);
for l = 1:num_FFTs % Generate averaged mag-squared
% waitbar2(l/num_FFTs); % data from NH block FFTs.
l
n = [start:stop];
temp = v.*s(n);
S = fft(temp);
mag_S_sqrd = real(S(1:N/2).*conj(S(1:N/2)));
sum_mag_S_sqrd = sum_mag_S_sqrd + mag_S_sqrd;
start = stop + 1;
stop = stop + N;
end

% close(h)
avg_mag_S_sqrd = sum_mag_S_sqrd/num_FFTs; % average.
MF = flipud(avg_mag_S_sqrd); % "time reverse" data to prepare
N1 = Fc*N/Fs; % for dama-mf code.
% Record index of carrier frequency.
end

if window
utype = ['ha'];
else
utype = ['re'];
end
fname = ['pg' int2str(Rc_DAMA/Rb_DAMA) utype];
mver = version if (mver(1) == '5')
eval(['save -v4 ' fname ' MF N1 N'])
else
eval(['save ' fname ' MF N1 N'])
end

% Variable Description
% Name Description Purpose
%---------------------------------------------------------------
% ON Program Control Used to turn ON/OFF Program Options
% OFF Program Control Used to turn ON/OFF Program Options

63
% ERR
% spreading_opt
% window
% Fc_DAMA
% Fs
% Fc
% Rb_DAMA
% Rc_DAMA
% samples_per_bit
% samples_per_chip
% N
% w
% num_FFTs
% M
% msg
% data
% s
% PN_code
% start
% stop
% l
% h
% num_mag_S_sqrd
% S
% mag_S_sqrd
% avg_mag_S_sqrd
% MF
% type
% fname
% mver
%-------------------------------

Program Control
Used in disaster recovery

Program Control
Used to turn ON/OFF spreading

Program Control
Used to turn ON/OFF windowing

Program Parameter
DAMA Carrier Frequency - for the purposes of this program it is used to set the reference index.

Program Parameter
Sampling Frequency

Program Parameter
Carrier Frequency - in this program it is set to the value of Fc_DAMA.

Program Parameter
Bit Rate

Program Parameter
Chip Rate

Calculated Parameter Each bit is represented by # of samples

Calculated Parameter Each chip is represented by # of samples.

Program Parameter Length of FFT block

Calculated Parameter window coefficients

Program Parameter Number of Iterations

Calculated Parameter The number of bits required in the data vector.

Calculated Vector The actual sinusoidal signal - later it is BPSK modulated.

Calculated Vector Binary data stored as (-1,1)

Calculated Vector BPSK SS carrier

Calculated Vector The pseudo-random noise vector to cause spreading.

Program Parameter Used in indexing

Program Parameter Used in indexing

Program Control Used in FOR loop

Program Control Handle to figure

Calculated Vector Holds sum of magnitude squared data from FFT.

Calculated Vector Holds FFT data for current iteration

Calculated Vector Holds magnitude squared data from FFT for current iteration.

Calculated Vector Holds the average mag_S_sqrd vector.

Calculated Vector Frequency reversed - think of it as time reversed data.

Program Control Type of window employed for inclusion into file name.

Program Control Filename

Program Control mver(1) holds matlab version.
plot_dama_data.m

001 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
002 % PLOT_DAMA_DATA plot_dama_data
003 %
004 % Description: This function provides a variety of tools for DAMA data
005 % visualization using the file saved in DAMA.M
006 %
007 % Call Syntax: plot_dama_data
008 %
009 % Programmer: Phillip De Leon
010 %
011 % Creation Date: December 31, 1995
012 % Last Revision: July 1, 1997
013 %
014 % Required subroutines:
015 %
016 % Notes: Assume workspace (DAMA_DATA.MAT) has already been loaded.
017 %
018 % References:
019 %
020 % Copyright (c) 1998 by Phillip De Leon, All Rights Reserved
021 %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
022
023 Mcfg;
024
025 selection = menu('Select a Plot',...
026 'Estimation Ranges',...
027 'Estimation Histograms',...
028 'Estimation Accuracy',...
029 'Exit');
030
031 % ---------------------
032 % Estimation range
033 % ---------------------
034 if (selection == 1)
035     i = find(est_data(1,:)); % find non-zero elements
036     max_neg_est_error = ((min(i)-1) * Fs / N) - Fe; % 1 <= i <= N but need 0 <= i <= N-1
037     max_pos_est_error = ((max(i)-1) * Fs / N) - Fe;
038     plot([snr(1) snr(1)], [max_neg_est_error max_pos_est_error]);
039     hold on
040     for m = 2:length(snr)
041         i = find(est_data(m,:)); % find non-zero elements
042         max_neg_est_error = ((min(i) - 1) * Fs / N) - Fe;
043         max_pos_est_error = ((max(i) - 1) * Fs / N) - Fe;
044         plot([snr(m) snr(m)], [max_neg_est_error max_pos_est_error]);
045     end;
046     plot([-100 100], [est_tolerance est_tolerance],':')
047     plot([-100 100], [-est_tolerance -est_tolerance],':')
048     hold off;
049     ylabel('Estimation error (Hz)');
050     xlabel('SNR (dB)');
051     if (window)
052         title(['Frequency Estimation Ranges (Rc=', sprintf('%d',Rc_DAMA), ...
053             ', N=', sprintf('%d', N), ', Hamming window)']);
054     else
055         title(['Frequency Estimation Ranges (Rc=', sprintf('%d',Rc_DAMA), ...
056             ', N=', sprintf('%d', N), ', Rectangular window)']);
057     end;
058     [i,j] = find(est_data);
059     Ymin = min(j);
060     Ymax = max(j);

65
axis([snr(1)-10, snr(length(snr))+10, 1.1*min(Ymin, -est_tolerance), 1.1*max(Ymax, est_tolerance)]);

% Estimation histogram

elseif (selection == 2)
for m = 1:length(snr)
    bar([0:N/2-1]*Fs/N, est_data(m,1:N/2));
    hold on;
    plot([0:N/2-1]*Fs/N, est_data(m,1:N/2),'+');
    plot([Fc,Fc],[0 1.1*max(est_data(m,1:N/2))],'b:');
    plot([Fc+est_tolerance,Fc+est_tolerance],[0 1.1*max(est_data(m,1:N/2))],'r:');
    plot([Fc-est_tolerance,Fc-est_tolerance],[0 1.1*max(est_data(m,1:N/2))],'r:');
    hold off;
    ylabel('Occurences')
    xlabel('Estimation Frequency (Hz)')
    if (window)
        title(['Frequency Estimation for SNR of ',sprintf('%g', snr(m)), ...
              'dB (Rc=',sprintf('%d',Rc_DAMA),', Hamming window)']);
    else
        title(['Frequency Estimation for SNR of ',sprintf('%g', snr(m)), ...
              'dB']);
    end;
    axis([0.96*(Fc-est_tolerance) 1.05*(Fc+est_tolerance) 0 1.1*max(est_data(m,1:N/2))]);
    disp('Hit any key to plot next histogram...');
pause;
end;

% Statistical Accuracy

elseif (selection == 3)
    lower_index_bound = ceil(N*(Fc-est_tolerance)/Fs)+1 % 1 <= lower_index_bound <= N
    upper_index_bound = floor(N*(Fc+est_tolerance)/Fs)+1 % 1 <= upper_index_bound <= N
    pause
    accuracy = zeros(length(snr),1);% 1
    for m = 1:length(snr)
        number_accurate_estimates=sum(est_data(m,lower_index_bound:upper_index_bound));
        accuracy(m) = number_accurate_estimates / number_of_estimates;
    end;
    plot(snr,accuracy,'k')
    xlabel('SNR (dB)');
    ylabel('Proportion of Estimates in Range');
    title('Estimation Accuracy');
    grid;
else
    return;
end;

% plot_dama_data

plot_dama_data
wsands4.m

001 % White Sands Data Collection Code ver 4.0
002 % Started on 6/26/98
003 % Fill in comments. --> Still need to comment
004 %
005 % Signal Vector Descriptions:
006 %
007 % 1: Rb = 1000 bits/sec  Rc = 100000 chips/sec
008 % 2: Rb = 1000 bits/sec  Rc = 200000 chips/sec
009 % 3: Rb = 1000 bits/sec  Rc = 100000 chips/sec
010 % 4: Rb = 1000 bits/sec  Rc = 400000 chips/sec
011 %
012 % Revision History:
013 %
014 % 7.  
015 % Ver 1.0:  Baseline, one file generated per user input
016 % Ver 2.0:  Four "useful" files generated at once, no user
017 % input. Some code cleaned up (vectorized).
018 % Ver 3.0:  More vectorization, utilizes MATLAB's filter
019 % function. Vectors are pre-allocated.
020 % Ver 3.01:  Changed code so that # of bits may be individually
021 % selected.
022 %
023 % Ver 4.0:  To allow for larger data file generation, a menu
024 % system is implemented so that only one data file
025 % is generated. This compensates for memory
026 % problems. Edit file for different spread/data
027 % rates.
028 % Ver 4.01:  "2047" NASA PN sequence took to long to generate
029 % so the sequence is generated offline for faster
030 % performance. This restricts resulting binary file
031 % length to 2meg.
032 %
033 % Last Update: 7/13/98
034 % Written by: Bradley James Scaife
035 %
036 timer = cputime;
037 preamble_length = 5000;
038
collection = menu('Please Select File to be
039 Generated:', '1k_100', '1k_20', '1k_10', '1k_40');
040
if collection == 1
041 % Generate file one
042 %%%%%%%%%%%%%%%%%%%%
043 % Message One Parameters
044 %%%%%%%%%%%%%%%%%%%%
045 msg_len1 = input('Enter Message Length One (bits): ') ;
046 msg_len1 = 30e3; %Restricted value - only change if spread vector code is altered.
047 Rb1 = 1000;   Rc1 = 100000;
048
049 % Calculated Parameters: Message One
050 %%%%%%%%%%%%%%%%%%%%
051 spread_factor1 = ceil(Rc1/Rb1);  % Set as an integer.
052
053 % Preallocate MSG1 vector
054 %%%%%%%%%%%%%%%%%%%%
055 msg1_init = zeros(msg_len1,1);  msg1 =
056 zeros(msg_len1*spread_factor1,1);
057 %spreading_vector1 = zeros(msg_len1*spread_factor1,1);
058
059 % MSG 1 and Spreading Vector Generation
060 %%%%%%%%%%%%%%%%%%%%

67
061 rand('seed',0);
062
063 msg1_init = round(rand(msg_len1,1));
064
065 msg1 = upsamp(msg1_init,spread_factor1);
066 msg1 = filter(ones(spread_factor1,1),1,msg1);
067 clear msg1_init
068
069 load svec
070
071 % Generate s1
072 disp('Generating s1...')
073 s1 = 256*xor(msg1,spreading_vector);
074
075 % Binary File Generation
076 disp('Generating binary file...')
077 disp('Inserting preamble...')
078 disp('Inserting signal vector...')
079
080 data_out1 = [zeros(1,preamble_length) s1];
081 fid=fopen('1k_100.bin','wb');
082 fwrite(fid,data_out1,'int8');
083 fclose(fid);
084
085 elseif choice == 2
086 % Generate File 2: Per definition in header above.
087 disp('Generating s2...')
088 s2 = 256*xor(msg2,spreading_vector);
089
090 % Calculated Parameters
091 spread_factor2 = ceil(Rc2/Rb2);
092
093 msg_len2 = input('Enter Message Length Two (bits): ');
094 Rb2 = 1000; Rc2 = 20000;
095
096 % Preallocate MSG2 vectors
097
098 msg2_init = zeros(msg_len2,1);
099
100 msg2 = zeros(msg_len2*spread_factor2,1);
101 spreading_vector2 = zeros(msg_len2*spread_factor2,1);
102
103 % Message and Spreading Vector Generation
104 disp('Generating s2...')
105 s2 = 256*xor(msg2,spreading_vector);
106
107 % Binary File Generation
108 disp('Generating binary file...')
109 disp('Inserting preamble...')
110 disp('Inserting signal vector...')
111
112 data_out2 = [zeros(1,preamble_length) s2];
113 fid=fopen('1k_200.bin','wb');
114 fwrite(fid,data_out2,'int8');
115 fclose(fid);
disp('Generating binary file...')
disp('Inserting preamble...')
disp('Inserting signal vector...')

data_out2 = [zeros(1,preamble_length) s2];

fid = fopen('1k_20.bin','wb');
fwrite(fid,data_out2,'int8');
fclose(fid);

elseif choice == 3

load avec

% Generate s3
disp('Generating s3...')
s3 = 255 xor(msg3,spreading_vector);

% Binary File Generation

data_out3 = [zeros(1,preamble_length) s3];

fid = fopen('1k_10.bin','wb');
fwrite(fid,data_out3,'int8');
fclose(fid);

else

load avec

% msg_len3 = input('Enter Message Length Three (bits): ');
msg_len3 = 200e3; % Restricted value - only change if spread vector code is altered.
Rb3 = 1000; Rc3 = 10000;

% Calculated Parameters
spread_factor3 = ceil(Rc3/Rb3);

% Preallocate MSG3 vectors
msg3_init = zeros(msg_len3,1);
msg3 = zeros(msg_len3*spread_factor3,1);
spreading_vector3 = zeros(msg_len3*spread_factor3,1);

% Message and Spreading Vector Generation
msg3_init = round(rand(msg_len3,1));
msg3 = upsamp(msg3_init,spread_factor3)';
msg3 = filter(ones(spread_factor3,1),1,msg3);
clear msg3_init;

% Generate s3
disp('Generating s3...')
s3 = 255 xor(msg3,spreading_vector);

% Binary File Generation

data_out3 = [zeros(1,preamble_length) s3];

fid = fopen('1k_10.bin','wb');
fwrite(fid,data_out3,'int8');
fclose(fid);

else

load avec

% msg_len4 = input('Enter Message Length Four (bits): ');
msg_len4 = 50e3; % Restricted value - only change if spread vector code is altered.
Rb4 = 1000; Rc4 = 40000;

% Generate File 4: Per definition in header above.
% Calculated Parameters

spread_factor4 = ceil(Rc4/Rb4);

% Preallocate MSG4 vectors
msg4_init = zeros(msg_len4,1);

msg4 = zeros(msg_len4*spread_factor4,1);

% spreading_vector4 = zeros(msg_len4*spread_factor4,1);

% Message and Spreading Vector Generation
msg4_init = round(rand(msg_len4,1));

msg4 = upsamp(msg4_init,spread_factor4);

msg4 = filter(ones(spread_factor4,1),1,msg4);
clear msg4_init

% Generate s4

disp('Generating s4...')
s4 = 255*xor(msg4,spreading_vector);

% Binary File Generation

disp('Generating binary file...')
disp('Inserting preamble...')
disp('Inserting signal vector...')
data_out4 = [zeros(1,preamble_length) s4];

fid = fopen('1k_40.bin','wb');
fwrite(fid,data_out4,'int8');
close(fid);

end
disp('All Done :) ')
run_time = cputime - timer
cap.mf.m

001 % Title:
002 % cap.mf.m
003 %
004 % Purpose:
005 % The purpose of this code is to generate estimation data similar to
dama.mf with the exception that this code is tailored to use data
captured during the White Sands Complex (WSC) experiment.
006 %
007 % Revision:
008 % 1.0 -- 11/20/98
009 %
010 % Revision History:
011 % none => baseline
012 %
013 % Author:
014 % Brad Scaife
015 %
016 % Notes:
017 % This code requires as input data that has been prepared by vsco_d2.m which
018 % prepares the captured data and generates a matrix of usable vectors (see
019 % vsco_d2 comments for more information). This code also relies on an index
020 % matrix that is generated by in_prp.m. In both cases these files have already been
021 % prepared and may simply be loaded following prescribed naming conventions. In
022 % the event that these data files have been lost though it was thought helpful to
023 % comment on how to regenerate them.
024 %
025 % Average runtime:
026 % 8 minutes
027 %
028 % clear all;
029 %
030 % Code Options
031 %
032 % use to toggle use of hamming window
033 % window = OFF;
034 % use to toggle use of matched filter
035 % matched_filter = ON;
036 % use to gain instantaneous frequency estimation
037 % insight = OFF;

041 % Code Parameters
042 %
043 % DO NOT CHANGE - this was the sample rate used.
044 Fs = 100e6;
045 % As per dama.mf definition - not ws definition.
046 ksnr = 1.5;
047 % +/- range of acceptable error in Hz.
048 est_tolerance = 3e3;
049 % Number of FFT's to average over - changing this will
050 % # of estimation attempts. Don't modify!!!
051 number_of_estimates = 1000;
052 % require changes to code mentioned in documentation above
053 % as well as the rerunning of this code.
054 %
055 % Constant used to obtain consistent data points - does not
056 % add to statistical meaning nor detract from it.
057 alpha = 2;
058 %
059 f_lo = 32.50e6;
060 f_hi = 32.90e6;
061 lower_bound_index = ceil(f_lo*N/Fs)+1;
062 starting_bound = lower_bound_index;
063
061 upper_bound_index = floor(f_hi*N/Fe)+1;
062 Rb_DAMA = 1e3;
063
064 % Program Flow
065 X:::::::::::::::
066 if window
067 wtype = ['h'];
068 else
069 wtype = ['r'];
070 end
071
072 menu_sel = menu('Select Data to Process:','
073 'SF=10, SNR1, F2',',...
074 'SF=10, SNR1, F3',',...
075 'SF=10, SNR2, F1',',...
076 'SF=10, SNR2, F2',',...
077 'SF=10, SNR2, F3',',...
078 'SF=10, SNR2, F5',',...
079 'SF=10, SNR3, F2',',...
080 'SF=20, SNR2, F3')
081
082 if menu_sel == 1
083 data_filename = ['c:\research\code\matlab\whites-2\wcsmat\snr1_f2' wtype];
084 eval(['load ' data_filename]);
085 num_col = size(x,2);
086 index_filename = ['c:\research\code\matlab\whites-2\cmb8_' int2str(num_col)];
087 eval(['load ' index_filename]);
088 iterations = choose(num_col,8);
089 Xsnr = -5;
090 snr = 40;
091 Rc_DAMA = 10e3;
092 Fc = 32.65e6;
093
094 elseif menu_sel == 2
095 data_filename = ['c:\research\code\matlab\whites-2\wcsmat\snr1_f3' wtype];
096 eval(['load ' data_filename]);
097 num_col = size(x,2);
098 index_filename = ['c:\research\code\matlab\whites-2\cmb8_' int2str(num_col)];
099 eval(['load ' index_filename]);
100 iterations = choose(num_col,8);
101 Xsnr = -5;
102 snr = 40;
103 Rc_DAMA = 10e3;
104 Fc = 32.70e6;
105
106 elseif menu_sel == 3
107 data_filename = ['c:\research\code\matlab\whites-2\wcsmat\snr2_f1' wtype];
108 eval(['load ' data_filename]);
109 num_col = size(x,2);
110 index_filename = ['c:\research\code\matlab\whites-2\cmb8_' int2str(num_col)];
111 eval(['load ' index_filename]);
112 iterations = choose(num_col,8);
113 Xsnr = 1.5;
114 snr = 45;
115 Rc_DAMA = 10e3;
116 Fc = 32.6e6;
117
118
119
120 elseif menu_sel == 4
121 data_filename = ['c:\research\code\matlab\whites-2\wcsmat\snr2_f2' wtype];
122 eval(['load ' data_filename]);

72
num_col = size(x,2);
index_filename = ['e:\researeb\eode\matlab\wbites\2\cmb8_' int2str(num_col)];
eval(['load ' index_filename]);
iterations = choose(num_col,8);
% snr = 1.5;
% snr = 45;
Rc_DAMA = 10e3;
Fc = 32.65e6;

elseif menu_sel == 5
data_filename = ['e:\researeh\eode\matlab\wbites\2\cmb8\' int2str(num_col)];
eval(['load ' index_filename]);
iterations = ehoose(num_col,8);
% snr = 1.5;
% snr = 45;
Rc_DAMA = 10e3;
Fc = 32.70e6;

elseif menu_sel == 6
data_filename = ['c:\researeh\eode\matlab\wbites\2\cmb8\' int2str(num_col)];
eval(['load ' index_filename]);
iterations = ehoose(num_col,8);
% snr = 1.5;
% snr = 45;
Rc_DAMA = 10e3;
Fc = 32.80e6;

elseif menu_sel == 7
data_filename = ['c:\researeh\eode\matlab\wbites\2\cmb8\' int2str(num_col)];
eval(['load ' index_filename]);
iterations = ehoose(num_col,8);
% snr = 2.2;
% snr = 50;
Rc_DAMA = 10e3;
Fc = 32.65e6;

else
data_filename = ['c:\researeh\eode\matlab\wbites\2\cmb8\' int2str(num_col)];
eval(['load ' index_filename]);
iterations = ehoose(num_col,8);
% snr = 1.5;
% Rc_DAMA = 10e3;
Fc = 32.70e6;
end
% Some Corrections for code operation
%:
if iterations >= 1000
  iterations = 1000;
end
else
  alpha = 2;
end

% Load Matched Filter
%:
if matched_filter
  if window
    wtype2 = ['ha'];
  else
    wtype2 = ['re'];
  end
  fname = ['pg' int2str(Rc_DAMA/Rb_DAMA) wtype2];
  eval(['load c:\research\code\matlab\damane-1\' fname])
end

% Process Begin
%:
N = 65536; % Reset N after loading matched filter - required.
% Preallocation
I = zeros(N,fft_avg);
% = zeros(N/2,fft_avg);
I_mag_squared = zeros(length(lower_bound_index:upper_bound_index),fft_avg);
I_mag_squared = zeros(N/2,fft_avg);
I_avg = zeros(length(lower_bound_index:upper_bound_index),fft_avg);
I_avg = zeros(N/2,fft_avg);
est_data = zeros(length(snr),length(lower_bound_index:upper_bound_index));
est_data = zeros(length(snr),N/2);

% Begin FFT Estimation Process
%:
for n = 1:iterations
  n
  temp = w(1,index(n,:));
  X = fft(temp);
  I = I(1:lower_bound_index:upper_bound_index,:);
  I = I(:,1:N/2,:);
  I_mag_squared = (X*conj(X)).';
  X_avg = (sum(I_mag_squared)./fft_avg).';
  if matched_filter
    MF_mag_X = conv(MF,X_avg);
  end
  k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
  if insight
    disp('Frequency found to be:');
    k(20791) = 100e6/64e3
    pause(10)
  end
  if matched_filter
    k = find(MF_mag_X(1:length(MF_mag_X)) == max(MF_mag_X(1:length(MF_mag_X))));
end
if (length(k) > 1)
    k = median(k);
end

else
    k = k - N1;
    k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
    if (length(k) > 1)
        k = median(k);
    end
end

est_data(1,k) = est_data(1,k) + 1; % Increment bin

est_data(1,:) = est_data(1,:) .* alpha; % Sponge data to look like a larger estimate

% -------------------------------
% Save Data in MATLAB 4.x format
% -------------------------------

x = version;
if (x(1)=='5') % running on MATLAB 5.x
    save -v4 cap_dat Fc Fs N N1 est_data est_tolerance number_of_estimates ...
    starting_bound snr window vtype2
else % running on MATLAB 4.x
    save cap_dat Fc Fs N N1 est_data est_tolerance number_of_estimates ...
    starting_bound snr window vtype2
end;
wsco_d2.m

001 % DAMA Test Signal Analysis
002 %
003 % Purpose:
004 % This code is to be used as driver code for wsco.m. This code
005 % converts captured whites sands files and converts them into
006 % usable length N blocks. Not entirely automated. Please read
007 % info in wsco.m for details on project purpose.
008 %
009 % Input:
010 % This code requires the DAMA test files named as s1,s2,...,sn.
011 %
012 % Output:
013 % Undecided at this point.
014 %
015 % Revision History:
016 %
017 % ver 1.0: baseline
018 % ver 2.0: Changed scope of code. This program is now to
019 % to be used to drive other code only.
020 % ver 2.5: Restructed the format data is to be saved in.
021 %
022 %
023 % Current Version - Date:
024 % 2.5 - 8/4/98
025 %
026 % Author:
027 % Brad Scaife
028 %
029 % Date:
030 % 7/23/98
031 %
032 % Notes:
033 % Remember to change the save filename at the end of the code. Sorry
034 % got to do a little work to run this one.
035 %
036 clear all
037 ON = 1;
038 OFF = 0;
039 window = OFF;
040
041 % Change to working directory
042 %
043 cd c:\research\data\damaus\1\1k_10\snr2\f3
044 %
045 % Code Options
046 %
047 capture_option = 0; % 0 for 50ksample data else 1 (for 100k)
048 %
049 % Code Parameters
050 %
051 num_files = 6; % 6- for snr1_f3; 9- for snr2_f3; 12- for snr3_f2
052 half = 65536;
053 short_cap = 50002;
054 long_cap = 100002;
055 load s1;
056 if length(s1) == long_cap
057 capture_option = 1;
058 else
059 capture_option = 0;
clear s1;
pack

% Load raw signals

k = 0;

h = waitbar2(0,'Loading files...');

while 1
    k = k+1;
    sk = ['s' int2str(k)];
    filename = sk;
    if ~exist(filename), break, end
    eval(['load ' filename])
end
close(h)

Y. Preallocation

x = zeros(half,(1+capture_option)*num_files);

cd c:\research\code\matlab\whites2

if capture_option
    h = waitbar2(0,'Parsing 100 kSample Files...');
    index = 1;
    if window
        W = hamm(half);
    else
        W = ones(half,1);
    end
    for k = 1:2:2*num_files
        waitbar2(index/num_files);
        varname = ['s' int2str(index)];
        temp = eval([varname]);
        index = index +1;
        x(:,k) = temp(1:half).*W; % For others
        x(:,k+1) = temp(length(temp)-half+1:length(temp)).*W; % For others
    end
close(h);
else
    h = waitbar2(0,'Parsing 50 kSample Files...');
    if window
        W = hamm(length(s1));
    else
        W = ones(length(s1),1);
    end
    for k = 1:num_files
waitbar2(k/num_files);
varname = ['s' int2str(k)];
temp = eval([varname]);
temp = temp+W;
temp = [temp;zeros(half - length(temp),1)];
x(:,k) = temp;
close(h); end

if (mlver(1) == '5') % Running on MATLAB 5.x
    save -v4 snr2_f3r x
else
    save snr2_f3r x
end
cd c:\research\code\matlab\whites'2\wscmat'2
%clear all
Title: prepcap.m

Purpose: The purpose of this code is to prepare DAMA captured signals for comparison against simulated results.

Revision: 1.0 -- 7/26/98
1.5 -- 8/2/98
2.0 -- 11/2/98

Revision History:

Author: Brad Scaife

Date: 7/26/98

Notes: This code requires input signals matrices that have been prepared by wsco_d.m and vector sequence matrices prepared by goob.m. Due to limited test set, the code makes some approximations that may or may not be valid. Therefore, this code should not be considered in any way a proof but rather a "ballpark" type of justification: Could it work in the real world?

clear all

ON = 1;
OFF = 0;

% Code Parameters

snr = 1:7; % SNR Ranges from So/N estimate.
Fc = 32.7e6; % Measured DAMA carrier - from WSC.
Fs = 100e6; % Burr-Brown Sampling Rate.
est_tolerance = 3e3; % +/- acceptable error.
N = 65536; % FFT block length.
number_of_estimates = 1000; % # of estimation attempts
fft_avg = 8; % Number of FFT's to perform estimation over.
alpha = 2; % Correction to number of estimates.
insight = 0;
lower_bound_index = 21291; % Index of lower search bound.
upper_bound_index = 21504; % Index of upper search bound.
starting_bound = lower_bound_index;
window = OFF;
matched_filter = ON;

% Preallocation

X_mag_squared = zeros(length(lower_bound_index:upper_bound_index),fft_avg);
X_avg = zeros(length(lower_bound_index:upper_bound_index),fft_avg);
est_data = zeros(length(snr),length(lower_bound_index:upper_bound_index));
if window
load c:\research\code\matlab\damane-1\pg10ha
else
load c:\research\code\matlab\damane-1\pg10re
end
Load SNR1_F2 Data Matrix (65536x12) and Combination Matrix (496x8)
load c:\research\code\matlab\vhites-2\snr1_f2
load c:\research\code\matlab\vhites-2\cmb8_12
vaitbar2(0,'Formulating SNR1 Estimation for f2...');
index = cmbo3; % Load unique index pattern matrix.
waitbar2(n/496);
temp = x(:,index(n,:)); % Select current index pattern.
I = fft(temp); % Perform 8 FFT's
I = I(lower_bound_index:upper_bound_index,:); % Restrict to search bound
I_mag_squared = (I.*conj(I)).';
X_avg = (sum(I_mag_squared)./fft_avg).'; % Sum and average.
k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
if insight
disp('Frequency found to be:');
k=20791+1000e6/64e3
pause(10)
end
if (length(k) > 1)
k = median(k);
disp('Oops!')
end
est_data(1,k) = est_data(1,k) + 1; % Increment bin
est_data(1,:) = est_data(1,:) .* alpha; % Sponge data to look like a larger estimate

clear x
clear index;
close(h);

Load SNR1_F3 Data Matrix (66536x12) and Combination Matrix (496x8)
load c:\research\code\matlab\vhites-2\snr1_f3
load c:\research\code\matlab\vhites-2\cmb8_12
h = waitbar2(0,'Formulating SNR1 Estimation for f3...');
for n = 1:495
index = cmbo3; % Load unique index pattern matrix.
waitbar2(n/496);
temp = x(:,index(n,:)); % Select current index pattern.
X = fft(temp); % Perform 8 FFT's
X = X(lower_bound_index:upper_bound_index,:); % Restrict to search bound
X_mag_squared = (X.*conj(X)).';
X_avg = (sum(X_mag_squared) ./ fft_avg).'; % Sum and average.
k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
if insight
    disp('Frequency found to be:')
    pause(10)
end
if (length(k) > 1)
    k = median(k);
    disp('oops')
end
est_data(2,k) = est_data(2,k) + 1; % Increment bin

est_data(2,:) = est_data(2,:) .* alpha; % Sponge data to look like a larger estimate

clear x

% Load SNR2_F1 Data Matrix (65536x12) and Combination Matrix (495x8)
load c:\research\code\matlab\whites-2\snr2_f1
load c:\research\code\matlab\whites-2\cmb8_12
h = waitbar2(0, 'Formulating SNR2 Estimation for f1...');

for n = 1:495
    index = cmbo3; % Load unique index pattern matrix.
    waitbar2(n/495);
    temp = x(:,index(n,:)); % Select current index pattern.
    X = fft(temp); % Perform 8 FFT's
    X = X(lower_bound_index:upper_bound_index,:); % Restrict to search bound
    X_mag_squared = (X.*conj(X)).';
    X_avg = (sum(X_mag_squared) ./ fft_avg).'; % Sum and average.
    k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
    if insight
        disp('Frequency found to be:')
        pause(10)
    end
    if (length(k) > 1)
        k = median(k);
        disp('oops')
    end
    est_data(3,k) = est_data(3,k) + 1; % Increment bin
end

est_data(3,:) = est_data(3,:) .* alpha; % Sponge data to look like a larger estimate

clear x
185 clear index;
186 close(b);
187
188
189 % Load SNR2_F2 Data Matrix (65536x12) and Combination Matrix (495x8)
190 X***********************************************************************
191 load c:\research\code\matlab\whites2\snr2_f2
192 load c:\research\code\matlab\whites2\cmb8_12
193 h = waitbar2(0,'Formulating SNR2 Estimation for f2...');
194
195 for n = 1:495
196    index = cmbo3; % Load unique index pattern matrix.
197    waitbar2(n/495);
198    temp = x(:,index(n,:)); % Select current index pattern.
199    X = fft(temp); % Perform 8 FFT's
200    X = X(lower_bound_index:upper_bound_index,:); % Restrict to search bound
201    X_mag_squared = (X.*conj(X)).';
202    X_avg = (sum(X_mag_squared) ./ fft_avg).'; % Sum and average.
203
204    k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
205    if length(k) > 1
206        k = median(k);
207        disp('ooops')
208    end
209
210    est_data(4,k) = est_data(4,k) + 1; % Increment bin
211
212 end
213
214 est_data(4,:) = est_data(4,:) .* alpha; % Sponge data to look like a larger estimate
215
216 clear x
217 clear index;
218 close(b);
219
220 % Load SNR2_F3 Data Matrix (65536x18) and Combination Matrix (1000x8)
221 X***********************************************************************
222 load c:\research\code\matlab\whites2\snr2_f3
223 load c:\research\code\matlab\whites2\mc_cmb2
224 h = waitbar2(0,'Formulating SNR2 Estimation for f3...');
225
226 for n = 1:1000
227    waitbar2(n/1000);
228    temp = x(:,index(n,:));
229    X = fft(temp); % Perform 8 FFT's
230    X = X(lower_bound_index:upper_bound_index,:); % Restrict to search bound
231    X_mag_squared = (X.*conj(X)).';
232    X_avg = (sum(X_mag_squared) ./ fft_avg).'; % Sum and average.
233
234    k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
235    if length(k) > 1
k = median(k);
disp('oomp')
end
est_data(5,k) = est_data(5,k) + 1; % Increment bin
clear x;
close(h);

% Load SNR2_F5 Data Matrix (65536x12) and Combination Matrix (495x8)
load c:\research\code\matlab\vhites-2\snr2_f5
load c:\research\code\matlab\vhites-2\cmb8_12
h = waitbar2(0,'Formulating SNR2 Estimation for f5...');
for n = 1:495
    index = cmbo3; % Load unique index pattern matrix.
    waitbar2(n/495);
    temp = x(:,index(n,:)); % Select current index pattern.
    X = fft(temp); % Perform 8 FFT's
    X = X(lower_bound_index:upper_bound_index,:); % Restrict to search bound
    X_mag_squared = (X.*conj(X)).';
    X_avg = (sum(X_mag_squared) ./ fft_avg).'; % Sum and average.
    k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
    if length(k) > 1
        k = median(k);
        disp('oomp')
    end
    est_data(6,k) = est_data(6,k) + 1; % Increment bin
end
est_data(6,:) = est_data(6,:) .* alpha; % Sponge data to look like a larger estimate

clear x
clear index;
close(h);

% Load SNR3_F2 Data Matrix (65536x12) and Combination Matrix (495x8)
load c:\research\code\matlab\vhites-2\snr3_f2
load c:\research\code\matlab\vhites-2\cmb8_12
h = waitbar2(0,'Formulating SNR3 Estimation for f2...');
for n = 1:495
    index = cmbo3; % Load unique index pattern matrix.
    waitbar2(n/495);
    temp = x(:,index(n,:)); % Select current index pattern.
    X = fft(temp); % Perform 8 FFT's
X = X(lower_bound_index:upper_bound_index,:); % Restrict to search bound
X_mag_squared = (X.*conj(X)).';
X_avg = (sum(X_mag_squared)./fft_avg).'; % Sum and average.
k = find(X_avg(1:length(X_avg)) == max(X_avg(1:length(X_avg))));
if insight
    disp('Frequency found to be: ')
    (k+20791)*100e6/64e3
    pause(10)
end
if (length(k) > 1)
k = median(k);
disp('ooops')
end
est_data(7,k) = est_data(7,k) + 1; % Increment bin
end
est_data(7,:) = est_data(7,:) .* alpha; % Sponge data to look like a larger estimate
clear x
clear index;
close(h);
mlver = version;
if (mlver(1) == 5) % Running on MATLAB 5.x
    save -v4 dama_cap Fs Fs snr est_tolerance N number_of_estimates ...
est_data lower_bound_index upper_bound_index
else % Running on MATLAB 4.x
    save dama_cap Fs Fs snr est_tolerance N number_of_estimates ...
est_data lower_bound_index upper_bound_index
end
Experiment One: Finding Probabilities and MSE estimates of estimating a complex sinusoid in noise.

Purpose: The purpose of this code is to determine and prove the relationship between the DAMA curves and actual MSE of estimation. This baseline test will provide insight into the simpler case of a complex sinusoid in noise which will then be extended to the more complex DAMA carrier case.

Programmer: Brad Scaife
Date: 2/14/99
Revision Date: 4/20/99
Current Revision: 1.10
Revision History:

Notes: See Porat. As per indicated in Porat, the results of estimation are valid only when the "rule of thumb" are satisfied. Thus any processing of snr's below the ROT are not valid with the theoretical curve.

Program Parameters:

% Normally set to 512.
% - Computational Resolution.
% - Basic DFT resolution.
% - Sampling frequency.
% - Sampling interval.
% - Sinusoid frequency.
% - Phase offset.
% - Amplitude of sinusoid.
% - Set as window function = see Porat.
% - As per Porat.

snr = [-20:.5:30];
number_estimates = 1000;

Calculated Program Parameters

% - Frequency estimation range as a function of basic DFT resolution.
% - Lower "accurate" estimation bound.
% - Upper "accurate" estimation bound.
% - Lower index bound.
% - Upper index bound.

clear all
clc

N = 512;
L = 8*N;
Nbase = N;
fs = 800e3;
Ts = 1/fs;
f = 200e3 + fs/(8*N);
stime = 0; stime = (N-1)/fs;
phi = 0;
A = 1;
jw = 1;
D = Nbase+Ts;

est_range = floor(fs/L)/2;
f_lo = f - est_range;
f_hi = f + est_range;
K_lo = ceil(f_lo*N/fs);
K_hi = floor(f_hi*N/fs);
if \( N = N_{\text{base}} \)
\[ k_{hi} = k_{lo}; \]
end

res_factor = \( N/L \);  \% Resolution Factor

% Preallocate
success = zeros(1,length(snr));

mse_calc = zeros(1,length(snr));
mse = zeros(1,length(snr));
rmse = zeros(1,length(snr));
rmse_calc = zeros(1,length(snr));

mse_sum = 0;
Xerr_sum = 0;

% Signal Generation, Finding of true frequency

s = csin_gen(f,phi,A,fs,stime,etime);  \% Verified power = 1.
signal_power = cov(s);
S = fft(s);
S_mag = abs(S);
true_ind = find(S_mag == max(S_mag))-1
f_true = true_ind/N*fs
true_ind = floor(f_true*N/fs)

disp('Press a key to continue...') pause

for n = 1:length(snr)

snr_mod = sqrt(cov(s)/(10^{-(snr(n)/10)}));  \% Standard Deviation of noise
No = Ts * snr_mod-2;
N = No = Ts * (2 + snr_mod-2)^2;

mse_calc(n) = (6*No*Jw)/(2 + A-2 * D-3);
rmse_calc(n) = sqrt(6*Jw*sqrt( cov(s)/(10^{-(snr(n)/10)}) )/(100*pi^2))/D;
rmse_calc(n) = (1/D)*sqrt(6*Jw*PG/(100*pi^2));

randn('seed',0);  
end

for k = 1:number_estimates

v = [randn(N,1) + j*randn(N,1)]*snr_mod/sqrt(2);

xcorr(s)
xcov(v)  \% Remove me
xcorr(10*log10(cov(s) / cov(v)))  \% Remove me
pause
y = s + v;
123 \text{Y} = \text{fft(y,L)};
124 \text{Y}_\text{mag} = \text{abs(Y)};
125 \% \text{Y}_\text{mag} \cdot \text{Y}_\text{mag}(1:\text{NI2}+1);
126 \text{max_ind} = \text{min}(\text{find(Y}_\text{mag} = \text{max(Y}_\text{mag})) - 1;
127 \text{f}_\text{found} = \text{max_ind}/\text{fs};
128 \text{mse}_\text{sum} = \text{mse}_\text{sum} + (\text{f}_\text{true} - \text{f}_\text{found})^2;
129 \% \text{err}_\text{sum} = \text{err}_\text{sum} + \text{abs(f}_\text{true} - \text{f}_\text{found});
130 \text{if} (\text{max_ind} > \text{k}_\text{lo} \& \text{max_ind} <= \text{k}_\text{hi})
131 \text{success}(n) = \text{success}(n) + 1;
132 \text{end}
133 \text{end}
134 \text{end}
135 \text{end}
136 \% \text{err}_\text{sum} = 0;
137 \text{mse}_\text{sum} = 0;
138 \text{end}
139 \text{success}(n) = \text{success}(n)/\text{number_estimates};
140 \text{rmse}_\text{calc} = \sqrt{\text{mse}_\text{calc}};
141 \text{mse}(n) = (\text{err}_\text{sum}/\text{number_estimates})^2;
142 \text{rmse}(n) = \sqrt{\text{mse}(n)};
ex2.m

%******************************************************************************
% 001 % Experiment Two: Finding Probabilities and MSE estimates of estimating
% 002 % a real sinusoid in real noise.
% 003 %
% 004 % Purpose: The purpose of this code is to determine and prove the
% 005 % relationship between the DAMA curves and actual MSE of
% 006 % estimation. This baseline test will provide insight into the
% 007 % simpler case of a complex sinusoid in noise which will then
% 008 % be extended to the more complex DAMA carrier case.
% 009 %
% 010 % Programmer:  Brad Scaife
% 011 % Date:  3/18/99
% 012 % Revision Date:  3/18/99
% 013 % Current Revision:  1.0
% 014 % Revision History:
% 015 % 1.0 - Baseline
% 016 %
% 017 % Notes: See Porat. As per indicated in Porat, the results of
% 018 % estimation are valid only when the "rule of thumb" are
% 019 % satisfied. Thus any processing of snr's below the ROT are
% 020 % not valid with the theoretical curve.
% 021 %
% 022 %******************************************************************************
% 023 % clear all clc
% 024 %
% 025 % Program Parameters:
% 026 %******************************************************************************
% 027 % N = 65536; % Normally set to 512.
% 028 % Nbase = 65536; % Basic DFT resolution.
% 029 % fs = 800e3; % Sampling frequency.
% 030 % Ts = 1/fs; % Sampling interval.
% 031 % f = 200e3 + fs/(4*N); % Sinusoid frequency.
% 032 % stime = 0; etime = (N-1)/fs;
% 033 %
% 034 % phi = 0; % Phase offset.
% 035 % A = 1; % Amplitude of sinusoid.
% 036 % Ju = 1; % Set as window function - see Porat.
% 037 % D = Nbase*Tfs;
% 038 %
% 039 %
% 040 % snr = [-20:.2:10]';
% 041 % number_estimates = 100;
% 042 %
% 043 % Calculated Program Parameters
% 044 %******************************************************************************
% 045 % est_range = floor(fs/Nbase)/2; % Frequency estimation range as a function of
% 046 % basic DFT resolution.
% 047 % f_lo = f - est_range; % Lower "accurate" estimation bound.
% 048 % f_hi = f + est_range; % Upper "accurate" estimation bound.
% 049 % k_lo = ceil(f_lo*N/fs); % Lower index bound.
% 050 % k_hi = floor(f_hi*N/fs); % Upper index bound.
% 051 %
% 052 % if N == Nbase
% 053 % k_hi = k_lo;
% 054 % end
% 055 %
% 056 % res_factor = N/Nbase; % Resolution Factor
% 057 %
% 058 % Preallocate
% 059 %******************************************************************************
% 060 % success = zeros(1,length(snr));
061 mse_calc = zeros(1,length(snr));
062 mae = zeros(1,length(snr));
063 rmse = zeros(1,length(snr));
064 rmse_calc = zeros(1,length(snr));
065 mse_sum = 0;
066 Xerr_sum = 0;
067
068 % Signal Generation, Finding of true frequency
069 X***********************************************************************
070 s = sinu_gen(f, phi, A, fs, stime, etime); % Verified power = 1.
071 signal_power = cov(s);
072 S = fft(s);
073 S_mag = abs(S);
074 Xtrue_ind = find(S_mag == max(S_mag)) - 1
075 Xf_true = true_ind/N*fs
076 Xpause
077 f_true = f;
078 % true_ind = floor(f_true*N/fs)
079
080 % Display Parameters
081 X*********************************************************
082 disp(sprintf('True Frequency: %10.6f Hz', f_true))
083 disp(sprintf('Base Points: %d', Nbase))
084 disp(sprintf('DFT Points: %d', N))
085 disp(sprintf('Calculation DFT Resolution: %10.5f Hz', fs/N))
086 disp(sprintf('Resolution Factor: %d', res_factor))
087 disp(sprintf('Estimation Range: %10.5f Hz', est_range))
088 disp(sprintf('Upper Index Bound: %d', k_hi))
089 disp(sprintf('Press a key to continue...') pause
090
091 for n = 1:length(snr)
092 % Current SNR to be tested.
093 snr(n) = sqrt(cov(s)/(10^(-snr(n)/10))); % Standard Deviation of noise
094 % No = Ts * (2 + snr_mod^2)^2/2;
095 No = Ts * snr_mod^2;
096 mse_calc(n) = (24*No*Jw)/((2*pi)-2 • A-2 • o-3);
097 % rmse_calc(n) = (1/D)*sqrt(6•Jw•PG/(100•pi-2))/D;
098 % err_sum = err_sum + abs(f_true - f_found);
099
100 for k = 1:number_estimates
101 v = randn(N,1) * snr_mod;
102 Y = fft(y);
103 Y_mag = abs(Y);
104 Y_mag_p = Y_mag(1:N/2 + 1);
105 max_ind = min(find(Y_mag_p == max(Y_mag_p))) - 1;
106 f_found = max_ind/N*fs;
107 mse_sum = mse_sum + (f_true - f_found)^2;
108 % err_sum = err_sum + abs(f_true - f_found);
109 if (max_ind >= k_lo & max_ind <= k_hi)

success(n) = success(n) + 1;
end

mse(n) = mse_sum / number_estimates;
rmse(n) = sqrt(mse(n));
err_sum = 0;
mse_sum = 0;
success(n) = success(n)/number_estimates;
end
rmse_calc = sqrt(mse_calc);
Experiment Three: Finding Probabilities and MSE estimates of estimating a BPSK carrier in real noise.

Purpose: The purpose of this code is to determine and prove the relationship between the DAMA curves and actual MSE of estimation. This test is an extension of experiments one and two where a BPSK carrier is under test.

Programmer: Brad Scaife
Date: 3/30/99
Revision Date: 3/30/99
Current Revision: 1.0
Revision History:

1.0 - Baseline

Notes: See Porat. As per indicated in Porat, the results of estimation are valid only when the "rule of thumb" are satisfied. Thus any processing of snr's below the ROT are not valid with the theoretical curve.

clear all clc

%-------------------
% Program Parameters
%-------------------
N = 512;
L = 2*0 + N;
A = 1;
Jw = 1;
fft_avg = 26;

%-------------------
% Communication System Parameters
%-------------------
Fs = 800e3; % output signal sampling freq. (samples/s)
Fc = 178e3; % BPSK carrier frequency in Hz. (cycles/sec)
kc = floor(Fc*L/Fs);
Rb = 10e3; % data rate (bits/s) Fs/Rb must be integer
samples_per_bit = Fs/Rb; % must be integer
D = N/Fs;

%-------------------
% Simulation Parameters
%-------------------
number_of_estimates = 10000; % # of frequency estimates to perform for each SNR typically 10000
snr = [-12:2:14];
msg = zeros(N,1);
x = zeros(N,1);
x = zeros(N,1);

%-------------------
% Display Info
%-------------------
disp(sprintf('Sampling Frequency Fs: %6.16f',Fs));
disp(sprintf('Carrier Frequency Fc: %5.15f',Fc));
disp(sprintf('FFT Resolution (Data Supported): %5.16f',Fs/N));
disp(sprintf('FFT Computational Resolution: %5.15f',Fs/L));
```matlab
pause
%
% Begin Iterative SNR Loop
%------------------------

for k = 1:length(snr)
    rand('seed',1000);
    randn('seed',0);
    mse_sum = 0;
    noise_power = (A^2/2)/(10^(-snr(k)/10));
    No = (noise_power) / Fs;
    help_factor = 1;
    mse_calc(k) = (24*No*W)/(help_factor*(2*pi)^2 * (A^2/(4*Rb)) + D^3);
    for l = 1:number_of_estimates
        R_mag_sum = zeros(L/2,1);
        for n = 1:fft_avg
            % Generate BPSK Signal
            msg = A*[cos(2*pi*([0:N-1]*Fc/Fs))];
            data = filter(ones(samples_per_bit,1),1,upsamp ... ((-1).*(round(rand(ceil(N/samples_per_bit),1))), ... samples_per_bit);
            data = data(1:length(msg));
            s = msg .* data;
            noise = randn(length(msg),1) .* sqrt(eov(s)/(10^(-snr(k)/10)));
            r = s + noise;
            r = r ./ sqrt(eov(r));
            R = fft(r,L);
            R_mag_sum = R_mag_sum + R(1:L/2).*conj(R(1:L/2));
        end
        R_mag = R_mag_sum ./ fft_avg;
        kmax = min(find(R_mag == max(R_mag)));
        f_est = (kmax-1)/L*Fs;
        mse_sum = mse_sum + (Fc - f_est)^2;
        mse(k) = mse_sum/number_of_estimates;
        rmse(k) = sqrt(mse(k));
        rmse_calc(k) = sqrt(mse_calc(k));
    end
end
clf
```
123 plot(snr, rmse_calc, '--')
124 hold on
125 plot(snr, rmse)
126 hold off
127 grid
B  Motorola DSP 56303EVM Code

rev30.asm

001  ; REV 3.0
002
003  ; Just for convenience - delete later!!! Turns on/off D/A codec
004  ; bclr  #19,x:M_CRBO ;Disable Rx on A-codec
005  ; bclr  #18,x:M_CRBO ;Used to disable Tx interrupt
006
007
008  opt now
009
010  ; nolist
011  include 'icequ.asm'
012  include 'intequ.asm'
013  include 'ada_equ.asm'
014  include 'vectors.asm'
015  include '7819equ.asm'
016  ;list
017
018  :****************************************************************************
019  ; Initial Layouts: This section of code sets up the D/A memory resources,
020  ; the program memory resources and defines the FFT macro.
021  :****************************************************************************
022  include 'CS4216.asm'  ;D/A Memory Resources
023  include 'fftr2cn.asm' ;FFT Macro
024  include 'convm.asm'  ;Convolution Macro
025  include 'mlayout.dat' ;Memory Layout
026
027  :****************************************************************************
028  ; Fast Interrupt - IRQB
029  :****************************************************************************
030  org  pli:I_IRQB
031  movep y:BB7819_DR,x:(r0)+
032  org  pli:I_IRQB+1
033  bset  #0,x:FLAGS
034
035  org  p:$100
036  START
037  main
038
039  :****************************************************************************
040  ; Set Operating Frequency
041  :****************************************************************************
042  movep  #CLK_RATE,x:M_PCTL ;Set PLL and Chip Operating Frequency
043
044  :****************************************************************************
045  ; Set Operating Parameters of DSP66303
046  :****************************************************************************
047  move  #OP_MODE,omr  ;Set Operating Mode of 303
048
049  :****************************************************************************
050  ; Setup Stack
051  :****************************************************************************
052  movec  #0,sp ;clear hardware stack pointer
053  move  #STACK,r6 ;initialise stack pointer
054  move  -$1,m6 ;linear addressing
055
056
057
058  :****************************************************************************
Set AAR Wait States for External Memory (32k) and A/D Codec

;*****************************
include 'vs_set.asm'; Set Wait States

;*****************************
set Up IRQB Interrupt Parameters. IRQB is the interrupt designated to
the A/D Codec.

;*****************************
or i #003, mr ; Mask all interrupts until needed.
include 'core_ipl.asm'; Set IRQB Interrupt Parameters

;*****************************
AAR2 equ 0

movep $fffc21 ; Compare Upper 12 bits to fffxxx
movep #AAR2, x:M_AAR2 ; Setup AAR2

jsr INIT ; Register Initialization Routine
andi #$fc, mr ; Re-enable all interrupts

main_loop

jclr #0, x:FLAGS .; Wait for Sample In
bclr #0, x:FLAGS
jsr process_sample
jmp main_loop

process_sample

clr a
move x:SAMPLE_COUNTER, a0
dec a
move a0, x:SAMPLE_COUNTER
tst a
jne GET_NEXT_SAMPLE
ori #003, mr ; Disable Interrupts

jsr WIN_N_SCALE
jsr COMPUTE_FFT
jsr AVG_FFT
andi #0fe, mr ; Enables only 800k A/D

movep #IPRC, x:M_IPRC ; Re-enable A/D Codec

GET_NEXT_SAMPLE
rts

; Subroutines:
;*****************************
include 'comp_fft.asm'
include 'vsc.asm'
include 'avg_fft.asm'
include 'init.asm'
include 'comp_fft.asm'
include 'iprc.asm'
include 'sinvigd.asm'
include 'msd_init.asm'
echo

end
mlayout.dat

001 ;******************************************************************************
002 ;mlayout.DAT: This data file is used with rev1.ASM to lay things out in memory
003 ;
004 ; Notes: For use with rev 2.1 code.
005 ;******************************************************************************
006 ; References:
007 ; DSP56300 Family Manual (300FM)
008 ; DSP66303 User's Manual (303UM)
009 ;******************************************************************************
010 ; Equates:
011 ;******************************************************************************
012 ; S6303 Processor Operating Parameters Control
013 ;******************************************************************************
014 ;******************************************************************************
015 ; CLK_RATE equ $040004 ;Chip Operating Clock - See Section 9.3 300FM
016 ;******************************************************************************
017 ;******************************************************************************
018 ; OP_MODE equ $389 ;Chip Operating Mode
019 ;******************************************************************************
020 ;******************************************************************************
021 ; FS equ 32000 ;Please set the same as D/A sample rate.
022 ;******************************************************************************
023 ;******************************************************************************
024 ;******************************************************************************
025 ;******************************************************************************
026 ;******************************************************************************
027 ;******************************************************************************
028 ;******************************************************************************
029 ;******************************************************************************
030 ;******************************************************************************
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055 ;******************************************************************************
056 ;******************************************************************************
057 ;******************************************************************************
058 ;******************************************************************************
059 ;******************************************************************************
060 ;******************************************************************************

96
061 MAX_VAL ds 1 ;Maximum value storage
062 MAX_LOCATION ds 1 ;Holds address of max location
063 INT_DELTA ds 1 ;Delta for Carrier Reconstruction.
064 FRACT_DELTA ds 1 ;Delta for Carrier Reconstruction.
065 R0_STORE ds 1 ;r0 storage
066 R1_STORE ds 1 ;r1 storage
067 R2_STORE ds 1 ;r2 storage
068 R3_STORE ds 1 ;r3 storage
069 R4_STORE ds 1 ;r4 storage
070 R5_STORE ds 1 ;r5 storage
071 R7_STORE ds 1 ;r7 storage
072 M0_STORE ds 1 ;m0 storage
073 M1_STORE ds 1 ;m1 storage
074 M2_STORE ds 1 ;m2 storage
075 M3_STORE ds 1 ;m3 storage
076 M4_STORE ds 1 ;m4 storage
077 M5_STORE ds 1 ;m5 storage
078 M7_STORE ds 1 ;m7 storage
079 M5_STORE ds 1 ;m5 storage
080 M7_STORE ds 1 ;m7 storage
081 FLAGS ds 1 ;User Defined Flag Register
082 OUT_COUNTER ds 1 ;Output Sample Counter
083 CNV_MEM ds 1 ;For use in convolutional code.
084 STACK equ * ;Beginning of Stack
085
086 org x:$800
087 ;******************************************************************************
088 ; Magnitude Squared Data
089 ;******************************************************************************
090 MAG_SQ_DATA dsm POINTS/2
091
092 org x:$400
093 ;******************************************************************************
094 ; Generate Sine Wave Lookup Table
095 ;******************************************************************************
096 TAB dsm TABLE_SIZE
097 include 'sintab.asm'
098 sintab TABLE_SIZE,TAB
099
100 ; Y Memory:
101 ;******************************************************************************
102 org y:$0
103 ;******************************************************************************
104 ; Generate Hamming Window w/ Prescale
105 ;******************************************************************************
106 HAMM dsm POINTS ;Hamming Window table.
107 include 'hamming.asm'
108 hamming POINTS,HAMM
109
110
111 ; Build Twiddle factor lookup tables for FFT Routine
112 ;******************************************************************************
113 include 'sincos.asm' ;Twiddle factor macro - builds lookup tables
114 sincos POINTS,COEFF ;Build lookup tables.
115
116
117 ; Spectral Matched Filter
118 ;******************************************************************************
119 SMF dsm POINTS/2
120 org y:SMF
121 include 'smf20.dat'
123
124 ; Convolution Output
125 ;***********************
126 CNV_OUT dsm 2+POINTS-1
wsc.asm

01 ;***********************************************************************
02 ; win_m_scale Subroutine
03 ;
04 ; Purpose: The purpose of this subroutine is to scale the input data to avoid
05 ; overflow problems. This will have the effect of lowering the overall values
06 ; of the spectrum but will not alter the shape of the spectrum.
07 ;
08 ; In: x:(r0) - Sample Buffer
09 ; y:(r4) - Hamming buffer
10 ;
11 ; OUT: x:(r0) - Sample Buffer w/ Window, scale, and iteration
12 ; adjustments
13 ;
14 ; Alters: a,b,r0,r3,r4,x0,x1,y0,y1
15 ;
16 ; Written By: Brad Scaife
17 ; Date: 2/20/98
18 ; Platform: Motorola DSP56303
19 ; Calls: None
20 ;
21 ; This code is verified for use with version three code. See rev30.asm.
22 ;***********************************************************************
23 WIN_N_SCALE
24 
25 move x:(r0)+,x0 y:(r4)+,y0 ;Preload values.
26 do #POINTS/2-1,ND_SCALE 
27 mpyr x0,y0,a x:(r0)+,x1 y:(r4)+,y1 ;x'(x)=w(n)*scale/# iterations
28 mpyr x1,y1,b x:(r0)+,x0 y:(r4)+,y0 ;Second Iteration
29 move a,x:(r3)+ ;Store a into sample buffer
30 move b,x:(r3)+ ;Store b into sample buffer
31 ND_SCALE
32 mpyr x0,y0,a x:(r0)+,x1 y:(r4)+,y1 ;Loop clean up: Two mults and
33 mpyr x1,y1,b ;corresponding writes to memory
34 move a,x:(r3)+ ;Counters back to top of
35 move b,x:(r3)+ ;buffer
36 rts
comp fft.asm

01 ;****************************************************************************************
02 ; COMPUTE FFT Subroutine
03 ;
04 ; Purpose: The purpose of this subroutine is to compute the FFT of the input
05 ; signal and store it in memory.
06 ;
07 ; In:   r0,r1,r2,r3,r4,r5,m0,m1,m2,m3,m4,m5
08 ; Out:  x:(r1),r0,r1,r2,r3,r4,r5,m0,m1,m2,m3,m4,m5
09 ; Alters: Everything
10 ;****************************************************************************************
11 COMPUTE_FFT
12 move r0,x:RO_STORE
13 move r1,x:R1_STORE
14 move r2,x:R2_STORE
15 move r3,x:R3_STORE
16 move r4,x:R4_STORE
17 move r5,x:R5_STORE
18 move r7,x:R7_STORE
19 move m0,x:MO_STORE
20 move m1,x:M1_STORE
21 move m2,x:M2_STORE
22 move m3,x:M3_STORE
23 move m4,x:M4_STORE
24 move m5,x:M5_STORE
25 move m7,x:M7_STORE
26 move m6,x:M6_STORE
27 move n7,x:N7_STORE
28 fftr2cn POINTS,SAMPLE_DATA,FFT_DATA,COEFF
29 move x:M7_STORE,m7
30 move x:M5_STORE,m5
31 move x:M7_STORE,m7
32 move x:M5_STORE,m5
33 move x:M4_STORE,m4
34 move x:M3_STORE,m3
35 move x:M2_STORE,m2
36 move x:M1_STORE,m1
37 move x:M0_STORE,m0
38 move x:R7_STORE,r7
39 move x:R5_STORE,r5
40 move x:R4_STORE,r4
41 move x:R3_STORE,r3
42 move x:R2_STORE,r2
43 move x:R1_STORE,r1
44 move x:R0_STORE,r0
45 rts
avg_fft.asm

01 ; for use with rev 2.1 code only AVG_FFT
02
03 move x:(r1)+,x0 y:(r7)+,y0
04 do #$PONTS/2),END_TLOOP
05 mpy x0,x0,a x:(r2),y1
06 macr y0,y0,a
07 add y1,a
08 move x:(r1)+,x0 y:(r7)+,y0
09 move a,x:(r2)+
10
11 END_TLOOP
12 clr b
13 move x:FFT_COUNTER,b0
14 dec b
15 move b0,x:FFT_COUNTER
16 tst b
17 js eq GET_MAX_BIN
18
19 ;******************************
20 ; Prepare to perform next FFT iteration
21 ;******************************
22 move #PONTS,x1 ;Reload sample counter for next sample
23 move x1,x:SAMPLE_COUNTER ;buffering.
24
25 ; move #FFT_RESULT,r2 ;re-Setup FFT Result ptr
26 move #MAG_SQ_DATA,r2 ;re-Setup Mag Squared data ptr
27 move #FFT_DATA,r1 ;Setup FFT Data ptr
28 move r1,r7 ;Imag. Pointer to FFT Buffer
29
30 move #0,x0
31 do #PONTS,CLR_DAT ;Clear FFT Data buffer
32 move x0,x:(r1) ;Real
33 move x0,y:(r1)+ ;Imaginary
34 CLR_DAT
35
36 do #PONTS,CLR_SMP
37 move x0,x:(r0)
38 move x0,y:(r0)+
39 CLR_SMP
40 rts
get_bin.asm

01 ;************************************************************
02 ; GET_MAX_BIN Subroutine
03 ;
04 ; Purpose: The purpose of this subroutine is to determine the frequency bin
05 ; that has the largest component and then to determine the delta for the
06 ; sine wave generation routine.
07 ;
08 ; In:  x:(r2)
09 ; Out:  b
10 ; Alters:  b,x1,y1,r2
11 ;
12 ; Notes: For use with rev 2.1 code only!!
13 ;************************************************************
14 GET_MAX_BIN
15 ;************************************************************
16 ; Clean Up From GET_BIN Subroutine
17 ;************************************************************
18 move #POINTS,x0 ;Reload sample counter for next sample
19 move x1,x:SAMPLE_COUNTER ;buffering.
20 move #FFT_DATA,r1 ;re-Setup FFT Data ptr
21 move r1,r7 ;Imag. Pointer to FFT Buffer
22 move #FFT_RESULT,r2 ;re-Setup FFT Result ptr
23 move #MAG_SQ_DATA,r2 ;re-Setup Mag Sq Data ptr
24 ;************************************************************
25 ; Perform SMF Convolution
26 ;************************************************************
27 move r0,x:R0_STORE
28 move r1,x:R1_STORE
29 move r4,x:R4_STORE
30 move m0,x:M0_STORE
31 move m1,x:M1_STORE
32 move m4,x:M4_STORE
33 ;convm POINTS/2-1,MAG_SQ_DATA,SMF,CHV_OUT,CHV_MEM
34 move x:R0_STORE,r0
35 move x:R1_STORE,r1
36 move x:R4_STORE,r4
37 move x:M0_STORE,m0
38 move x:M1_STORE,m1
39 move x:M4_STORE,m4
40 ;************************************************************
41 move #CHV_OUT,r7
42 move #POINTS/2-2,m7
43 clr b
44 do #POINTS-1,ND_MAX
45 move x:(r7),x1 ;Bin Comparison
46 cmp x1,b ;b-x1
47 jlt NEW_MAX ;b will always hold max
48 jmp DUMMY
49
50 NEW_MAX
51 move x1,b ;Store New Max Location
52 move r7,x:MAX_LOCATION
53 DUMMY
54 move (r7)+
55 nop
56 ND_MAX
57 move x:MAX_LOCATION,b ;Subtract max location from base
123

124: nop ; - Reserved
125: nop
126:
127: jmp *
128: nop ; - SCI Receive Data
129:
130: jmp *
131: nop ; - SCI Receive Data w/ Exception Status
132:
133: jmp *
134: nop ; - SCI Transmit Data
135:
136: jmp *
137: nop ; - SCI Idle Line
138:
139: jmp *
140: nop ; - SCI Timer
141:
142: nop ; - Reserved
143: nop
144:
145: nop ; - Reserved
146:
147:
148: nop ; - Reserved
149: nop
150:
151:
152: jmp *
153: nop ; Host receive data full
154:
155:
156: jmp *
157: nop ; Host transmit data empty
158:
159: jmp *
160: nop ; Available for Host Command
161: jmp *
162: nop ; Available for Host Command
163: jmp *
164: nop ; Available for Host Command
165: jmp *
166: nop ; Available for Host Command
167: jmp *
168: nop ; Available for Host Command
169: jmp *
170: nop ; Available for Host Command
171: jmp *
172: nop ; Available for Host Command
173: jmp *
174: nop ; Available for Host Command
175: jmp *
176: nop ; Available for Host Command
177: jmp *
178: nop ; Available for Host Command
179: jmp *
180: nop ; Available for Host Command
181: jmp *
182: nop ; Available for Host Command
183: jmp *
184: nop ; Available for Host Command
move #FFT_RESULT-1,y1 ;location to get the actual index
move #MAG_SQ_DATA-1,y1 ;location to get the actual index
sub y1,b ;Equals index imax
move #OFFSET,y0 
sub y0,b 
mov b1,n5 
jar SINWGID ;and program
move #>ITERS,x1 ;Init FFT Counter
move xi,x:FFT_COUNTER ;Reset FFT counter for next iteration.
rts
SINWGID Subroutine

Purpose: The purpose of this subroutine is to generate a tone at a frequency based upon the delta value passed in from GET_BIN.ASM.

In: b

Out: n/a

Alters: a,x1,r5,n5,y0,

Notes:

For use with rev 2.1 code.

Initialization: D/A Codec and Setup Control Words. Only initialize the first time.

Sentinel: 

; Initialization: D/A Codec and Setup Control Words. Only initialize the first time.

setp #0,x:M_IPRC ;Disable A/D
andi #$fc,mr ;Enable all interrupts

;set up control words

move #TONE_OUTPUT,y0 ;set up control words
move y0,x:TX_BUFF_BASE+2
move #TONE_INPUT,y0
move y0,x:TX_BUFF_BASE+3

bset #1,x:FLAGS ;Set after initialization.

send_loop

setp #2,x:M_SSISRO,* ;wait for frame sync to pass
jclr #2,x:M_SSISRO,* ;wait for frame sync

move x:(r5)+n5,y0

clr a ;Test for end of duration of
move x:OUT_COUNTER,a0 ;samples out phase.

dec a
move a0,x:OUT_COUNTER

tst a
jeq restart

move y0,x:TX_BUFF_BASE ;transmit left
move y0,x:TX_BUFF_BASE+1 ;transmit right
jmp send_loop

restart

move #OUT_LENGTH,x1 ;Reset output duration counter.
move x1,x:OUT_COUNTER

rts
ws_set.asm

01 ;************************************************
02 ; Wait State Parameter Settings Routine
03 ;
04 ; Purpose: The purpose of this routine is to set the Bus Control Register (BCR)
05 ; to the proper number of wait states required by each AAR device. In the
06 ; DAMA Project, the AAR devices are:
07 ;
08 ; 32k SRAM
09 ; Burr-Brown Codec (Operating @ 800kHz for DAMA Project)
10 ;
11 ;************************************************
12 ;Wait State Settings:
13 ;************************************************
14 DEFAULT_WS equ $0f ;default are wait states
15 SRAM_WS equ $0f ;32k SRAM
16 FLASH_WS equ $00 ;FLASH
17 PERIPH_WS equ $0f ;A/D Peripheral board
18
19 20 AREA0 equ SRAM_WS
21 AREA1 equ FLASH_WS
22 AREA2 equ PERIPH_WS
23 AREA3 equ SRAM_WS
24
25 26 BBS equ $0 ;Bus State
26 BLH equ $0 ;Bus Lock Hold
27 BRH equ $0 ;Bus Request Hold
28
29 30 BCR equ (BBS<<21)+(BLH<<22)+(BRH<<23)+(DEFAULT_WS<<16)+
30 + (AREA3<<13)+ (AREA2<<10)+ (AREA1<<6)+ (AREAO<<2)
31
32 33 movep #BCR,x:M_BCR ;Initialize Bus Control Register
Macro Name: CONVM.ASM

Purpose: The purpose of this macro is to provide the convolution of two sequences stored in memory. The algorithm does a nested structure to minimize the memory required.

Programmer: Brad Scaife
Initial Date: 2/20/99
Current Rev: 1.0
Current Rev Date: 2/20/99
Revision History:
1.0 - Baseline

Legal Statement:
This DSP66xxx macro may be freely used with out the permission of the author. The author provides the code with the intent that it is not to be used where such use may endanger life and property.
Use of this macro code releases the author from ANY litigation both past, present, and future from ANY and ALL such liability claims.
Use of this code is expressly permitted at your own risk.

Resources Used:
Registers Used:
a, b, r0, r1, r4, n0, n4, m0, m1, m4, x0, x1, y1

Notes:
Please note that this revision of the code requires the two input sequences to be of equal length.

; Begin Calculation

move $xcoefs,r0
move $K-1,m0
move $hcoefs,r4
move $K-1,m4
move $result,r1
move $K_ALL,m1

move #0,x0
clr b x0,x:CNV_MEM
clr a

move x:(r0),x0 y:(r4),y1
do #K_ALL/2+1, FIRST
move b0,x:CNV_MEM
do x:CNV_MEM, END_F
mac x0, y1, a x: (r0)-, x0 y: (r4)+, y1

END_F

inc b
move #hcoefs, r4
macr x0, y1, a
move b0, n0
move a, x: (r1)+
move #hcoefs, r0
nop
nop
clr a
move (r0)+, n0
move x: (r0)-, x0 y: (r4)+, y1

FIRST

dec b
dec b
move #>1, x1
move x: (r0)-, x0 y: (r4)+, y1
do #K_ALL/2, LAST
move b0, x: CNV_MEM
do x: CNV_MEM, END_L
mac x0, y1, a x: (r0)-, x0 y: (r4)+, y1

END_L

move #hcoefs+1, r4
move x1, n4
move b0, x: (r6)+
move x1, b0
inc b
macr x0, y1, a
move b0, x1
move #hcoefs+K-1, r0
move x: -(r6), b0
move a, x: (r1)+
dec b
clr a
move (r4)+, n4
move x: (r0)-, x0 y: (r4)+, y1

LAST

endm
--- Buffer for talking to the CS4215 ---

org x:0
RX_BUFF_BASE equ *
RX_data_1_2 ds 1 ;data time slot 1/2 for RX ISR
RX_data_3_4 ds 1 ;data time slot 3/4 for RX ISR
RX_data_5_6 ds 1 ;data time slot 5/6 for RX ISR
RX_data_7_8 ds 1 ;data time slot 7/8 for RX ISR
TX_BUFF_BASE equ *
TX_data_1_2 ds 1 ;data time slot 1/2 for TX ISR
TX_data_3_4 ds 1 ;data time slot 3/4 for TX ISR
TX_data_5_6 ds 1 ;data time slot 5/6 for TX ISR
TX_data_7_8 ds 1 ;data time slot 7/8 for TX ISR
RX_PTR ds 1 ; Pointer for rx buffer
TX_PTR ds 1 ; Pointer for tx buffer
TONE_OUTPUT EQU HEADPHONE_EN+LINEOUT_EN+(4*LEFT_ATTN)+(4*RIGHT_ATTN)
TONE_INPUT EQU MIC_IN_SELECT+(15*MONITOR_ATTN)
CTRL_WD_12 equ NO_PREAMP+HI_PASS_FILT+SAMP_RATE_32+STEREO+DATA_16 ;CLB=0
CTRL_WD_34 equ IMMED_3STATE+XTAL1_SELECT+BITS_64+CODEC_MASTER
CTRL_WD_56 equ $000000
CTRL_WD_78 equ $000000
INIT subroutine

Purpose: The purpose of this subroutine is to initialize pointers to memory and clear out buffers.

In: none

OUT: none

Alters: r0,m0,r1,m1,r2,m2,r3,m3,r4,m4

Notes: For use with rev 3.0 code.

::: 

13 INIT
14 move #SAMPLE_DATA,r0 ;Setup Sample buffer ptr
15 move r0,r3 ;Alternate Sample buffer ptr
16 move #POINTS-1,m0 ;Setup Sample buffer mod
17 move m0,m3 ;Alternate Sample Buffer mod
18
19 move #0,x0
do #POINTS,CLEAR_SAMPLE ;Clear Sample Buffer
21 move x0,x:(r0) ;Real
22 move x0,y:(r0)+ ;Imaginary
23
24 move #FFT_DATA,r1 ;Setup FFT Data ptr
25 move r1,r7 ;Imag. Pointer to FFT Buffer
26 move #POINTS-1,m1 ;Setup FFT Data mod
27 move m1,m7 ;Imag. FFT Buffer mod
28
do #POINTS,CLEAR_DATA ;Clear FFT Data buffer
29 move x0,x:(r1) ;Real
30 move x0,y:(r1)+ ;Imaginary
31
32 CLEAR_DATA
33
34 ; move #FFT_RESULT,r2 ;Setup FFT Result ptr
35 move #MAG_SQ_DATA,r2 ;
36 move #POINTS/2-1,m2 ;Setup FFT Result mod
37 do #POINTS/2,CLEAR_MAGSQ ;Clear FFT Result buffer
38 move x0,x:(r2) ;Real
39 move x0,y:(r2)+ ;Imaginary
40 CLEAR_MAGSQ
41
42 move r7,x:IFFT_PTR ;Store IFFT for r7 reuse.
43 move m7,x:IFFT_MOD ;
44 move #CVN_OUT,r7 ;Setup Convolution Output ptr
45 move #2*POINTS-2,m7 ;Setup Conv. Output mod.
46 do #2*POINTS-1,CLEAR_CVN ;Clear Conv. Output
47 move x0,y:(r7)+
48 CLEAR_CVN
49 move x:IFFT_PTR,r7
50 move x:IFFT_MOD,m7
51
52 move #HAMM,r4 ;Setup Hamming ptr
53 move #POINTS-1,m4 ;Setup Hamming mod
54 move #TAB,r6 ;Sine Table
55 move #TABLE_SIZE-1,m5 ;Sine Table mod
56
57 move #POINTS,x1 ;Initialize Sample Counter
58 move x1,x:SAMPLE_COUNTER
59 move #>ITERS,x1 ;Init FFT Counter
60 move x1,x:FFT_COUNTER
61       move  x0,x:FLAGS ;Clear User Defined Flag Register
62
63       move  #OUT_LENGTH,x1 ;Set output duration counter.
64       move  x1,x:OUT_COUNTER ;
65
66       rts
hamming.asm

01 hamming macro points, hamm_loc
02 hamming ident 1, 2
03
04 py equ 3.141592654
05 FREQ_INC equ 2.0*py/Gcvf(points-1); frequency increment
06 SCALE_SHIFT equ GCVF(Glog(Gcvf(points))/Glog(2.0)); Shifts to Produce 1/POINTS
07 ;ITERATIONS equ 2; Number of FFT iterations to perform. There
08 ;exists a limit before overflow.
09 ;SCALE_FAC equ Gcvf(points)*Gcvf(ITERATIONS); Scale Factor
10
11 org y:hamm_loc
12 N set 0
13 dup points
14 dc (0.54-0.46*Gcos(FREQ_INC*Gcvf(N)))/Gcvf(points/2)
15 N set N+1
16 endm
17 endm; end of hamming macro
Core Interrupt Priority Configuration Routine:

Purpose: The purpose of this routine is to set the core Interrupt priorities. For the DAMA Project, only IRQB need concern us presently. Thus, only bits 6 to 3 are relevant. The following table suggests the proper settings:

<table>
<thead>
<tr>
<th>IBL2</th>
<th>IBL1-0</th>
<th>Enabled</th>
<th>Priority</th>
<th>No</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>00</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>01</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>10</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>11</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For details see 303UM:D-17.

Current Settings:
Currently IRQB is the only interrupt enabled and it has been set to priority level 2 (highest) and negative edge triggering.

Written By: Tim Bagget
Adapted By: Brad Scaife
Date: 3/22/98

Notes: For use with rev 2.1 code.

; Core Interrupt Priority and Configuration
IBM equ $1 ; IRQB trigger (0 level, 1 neg edge)
IBP equ $1 ; IRQB priority level 0, 1, or 2;
IBL equ (IBM<<2)+(IBP+1)&3
IPRC equ IBL<<M_IBLO&M_IBL ; Disabled for the time being.
move #IPRC,x:M_IPRC ; Initialize Interrupt Priority/Config
sintab.asm

01 sintab macro tasiz,tab_loc
02 sintab ident 1,2
03
04 pie equ 3.141592654
05 TAB_INC equ 2.0*pie/Gcvf(tasiz)
06
07 org x:tab_loc
08 N set 0
09 dup tasiz
10 dc Gsin(TAB_INC*Gcvf(N))/2.0
11 N set N+1
12 endm
13 endm
14 ;end sine table generation macro
7819equ.asm

1 BB_ADR    equ $0 ; DIP Switch Address SW1 ($0 - $3f)
2 BB7819_DR equ $FFFFFF80+BB_ADR ; ADS7819 Data Register
fftr2cn.asm

001 ; This program originally available on the Motorola DSP bulletin board.
002 ; It is provided under a DISCLAIMER OF WARRANTY available from
003 ; Motorola DSP Operation, 8501 Wm. Cannon Drive W., Austin, Tx., 78735.
004 ; Radix 2, In-Place, Decimation-In-Time FFT (fast).
005 ; Last Update 18 Aug 88 Version 1.0
006 ;
007 fftr2cn macro points, data, ddata, coef
008 fftr2cn ident 1, 0
009 ;
010 ; Radix 2 Decimation in Time In-Place Fast Fourier Transform Routine
011 ; Complex input and output data
012 ; Real data in X memory
013 ; Imaginary data in Y memory
014 ; Normally ordered input data
015 ; Normally ordered output data
016 ; Coefficient lookup table
017 ; -Cosine values in X memory
018 ; -Sine values in Y memory
019 ;
020 ; Macro Call - fftr2cn points, data, ddata, coef
021 ; points number of points (16-32768, power of 2)
022 ; data start of data buffer
023 ; ddata start of output data buffer
024 ; coef start of sine/cosine table
025 ;
026 ; Alters Data ALU Registers
027 ; x1 x0 y1 y0
028 ; a2 a1 a0 a
029 ; b2 b1 b0 b
030 ;
031 ; Alters Address Registers
032 ; r0 n0 m0
033 ; r1 n1 m1
034 ; r2
035 ;
036 ; Alters Program Control Registers
037 ; pc sz
038 ;
039 ; Uses 6 locations on System Stack
040 ;
041 ; Latest Revision - 18 Aug-88
042 ;
043 move #data, r0 ;initialize input pointer
044 move #points/4, n0 ;initialize input and output pointers offset
045 move n0, n4 ;
046 move n0, n7 ;initialize coefficient offset
047 move #points-1, m0 ;initialize address modifiers
048 move m0, m1 ;for modulo addressing
049 move m0, m4
050 move m0, m5
051 ;

115
061: Do first and second Radix 2 FFT passes, combined as 4-point butterflies

062:

063move  x:((0)+n0),x0

064trf x0,a  x:((0)+n0),y1

066dono0,two_pass

067trf y1,b  x:((0)+n0),y0

068add y0,a  x:((0)+n1),x1

069add x1,b  r0,r4

070add a,b  (r0)+n0

071sub b,a  b,x:((r0)+n0)

072trf x0,a  y:((r0),b

073sub y0,a  y:((r4)+n4),y0

074sub y0,b  x0,x:((r0)

075add a,b  y:((r0)+n0),x0

076sub b,a  b,x:((r0)

077trf x0,a  y:((r0),b

078add y0,a  y:((r0)+n0),y0

079add y0,b  x0,x:((r0)+n0)

080add a,b  y:((r0)+x0)

081sub a,b  a,y:((r4)+n4)

082trf x0,a  b,y:((r4)+n4)

083sub y0,a  x1,b

084sub y1,b  x:((r0)+n0),x0

085add a,b  y:((r0)+n0),y1

086sub b,a  b,x:((r0)+n4)

087trf x0,a  a,y:((r4)

088_towpass

089:

090: Perform all next FFT passes except last pass with triple nested DIT loop

091:

092move #points/8,n1  ;initialize butterflies per group

093move #4,n2  ;initialize groups per pass

094move #1,m2  ;linear addressing for r2

095move #0,m7  ;initialize C address modifier for

096:reverse carry (bit-reversed) addressing

097:

098do  #cvi(#log(points)/#log(2)-2.5),_end_pass  ;-1 ??? example: 7 passes for 1024 pt. FFT

099move #data,r0  ;initialize A input pointer

100move r0,r1  ;initialize A output pointer

101move n1,r2  ;initialize B input pointer

102move r0,r4  ;initialize B output pointer

103move (r1)+n1  ;initialize C input pointer

104move r1,r5  ;initialize pointer offsets

105move #coeff, r7  ;butterfly loop count

106lua (r2)+,n0  ;;loop BF-1 times and start Radix 2 DIT BF kernel

107move n0,n4  ;b=ar,a=ai-br•vi,lookup -sine and -cosine values

108move n0,n5  ;b=ar,a=ai-br•vi+bi•vr=ai', PUT bi'

109move (r2)  ;b=nai,a=2•ar-ar+br•vr+bi•vi=ar', PUT ar'

110move x:((r1),x1  ;y1=bi,b=ai+br•vi,

111move x:((r7)+n7),x0  ;y1=bi,b=ai+br•vi,

112mac x1,y0,b  y:((r1)+y1

113macr -x0,y1,b  y:((r0),a

114do  n2,_end_grp  ;ai again,b=ai+br•vi-bi•vr=bi

115do  r2,_end_bfy  ;bi'=ai+br•vi-bi•vr=bi

117subi,b,a  x:((r0),b  b,y:((r4)

118mac -x1,x0,b  x:((r0)+a  a,y:((r5)

119macr -y1,y0,b  x:((r1),x1

120subi,b,a  b,x:((r4)

121mac x1,y0,b  y:((r0),b

122macr -x0,y1,b  a,x:((r5)

116
123 _end_bfy
124 move (rl)+n1
125 subl b,a x:(rl),b y:(rl),b
126 mac -x1,x0,b x:(rl)+n0,a a,y:(rl)+y0
127 macr -y1,y0,b x:(rl),x1 y:(rl)+y0
128 subl b,a b,x:(rl)+n0 y:(rl),b
129 mac x1,y0,b x:(rl)+n0,x0 y:(rl)+x1,y1
130 macr -x0,y1,b a,x:(rl)+n1 y:(rl)+x0
131 _end_grp
132 move n1,b1
133 lsl b,n2,a1 ;divide butterflies per group by two
134 lsl a,b1,n1 ;multiply groups per pass by two
135 move a1,n2
136 _end_pass
137 ;
138 ; Do last FFT pass
139 ;
140 move #2,n0 ;initialize pointer offsets
141 move n0,n1
142 move n0,n4 ;output pointer A offset
143 move n4,n5 ;output pointer B offset
144 move #data,r0 ;initialize A input pointer
145 move #data,r4 ;initialize A output pointer
146 move r4,r2 ;save A output pointer
147 lua (r0)+,x1 ;initialize B input pointer
148 lua (r2)+,y0 ;initialize B output pointer
149 move #0,n4 ;bit-reversed addressing for output ptr. A
150 move n4,n5 ;bit-reversed addressing for output ptr. B
151 move #coef,r7 ;initialize C input pointer
152 move (r5)+n5 ;predecrement output pointer
153 move x:(rl),x y:(rl),y0 ;x1=br,y0=wi
154 move x:(rl),a y:(rl),b ;a=w,b=wi
155 do n2,_lastpass ;Radix 2 DIT butterfly kernel with one butterfly per group
156 mac x1,y0,b x:(rl)+n1,x0 y:(rl)+n1,y1 ;b=ai+bri+wr=bi',a=wi, PUT previous ar'
157 subl b,a x:(rl),b y:(rl),b
158 mac -x1,x0,b x:(rl)+n0,a a,y:(rl)+n0,x0 ;a=ar+bi, PUT ai'
159 subl b,a b,x:(rl)+n0 y:(rl)+n0
160 mac -y1,y0,b x:(rl),x1 y:(rl),y1 ;b=br'+x1=br, PUT br'
161 subl b,a b,x:(rl)+n0 y:(rl)+n0
162 _lastpass
163 move a,x:(rl)+n1
164 endm
165
This program originally available on the Motorola DSP bulletin board. It is provided under a DISCLAIMER OF WARRANTY available from Motorola DSP Operation, 6501 Wm. Cannon Drive W., Austin, Tx., 78735.

Sine-Cosine Table Generator for FFTs.

Last Update 25 Nov 86 Version 1.2

sincos macro points,coef
sincos ident 1,2
sincos - macro to generate sine and cosine coefficient lookup tables for Decimation in Time FFT
twiddle factors.
points - number of points (2 - 32768, power of 2)
coef - base address of sine/cosine table
negative cosine value in X memory
negative sine value in Y memory

Latest revision - 25-Nov-86

pi equ 3.141592654
freq equ 2.0*pi/6cvf(points)
org x:coef
set 0
dup points/2
dc -Ocos(0cvf(count)*freq)
set count+1
endm

org y:coef
set 0
dup points/2
dc -Ssin(0cvf(count)*freq)
set count+1
endm
endm ;end of sincos macro
Initialization constants to facilitate initialization of the CS4215

Copyright (c) MOTOROLA 1996

Semiconductor Products Sector

Digital Signal Processing Division

NO_PREAMP equ $100000
LO_OUT_DRV equ $080000
HI_PASS_FILT equ $008000

SAMP_RATE_9 equ $003800 ; 9.6 kHz sample rate
SAMP_RATE_48 equ $003000 ; 48 kHz sample rate
SAMP_RATE_32 equ $001800 ; 32 kHz sample rate
SAMP_RATE_27 equ $001000
SAMP_RATE_16 equ $000800
SAMP_RATE_8 equ $000000
STEREO equ $000400
DATA_8LIN equ $200300
DATA_9A equ $200200
DATA_8U equ $200100
DATA_16 equ $200000
IMMED_3STATE equ $000000
XTAL1_SELECT equ $100000 ; 24.576 MHz
XTAL2_SELECT equ $200000 ; 16.9344 MHz
BITS_64 equ $000000
BITS_128 equ $040000
BITS_256 equ $080000
CODEC_MASTER equ $020000
CODEC_TX_OFF equ $010000

CTRL_WD_12 equ NO_PREAMP_HI_PASS_FILT_SAMP_RATE_48+STEREO+DATA_16 ;CLB=0
CTRL_WD_34 equ IMMED_3STATE+XTAL1_SELECT+BITS_64+CODEC_MASTER
CTRL_WD_56 equ
CTRL_WD_78 equ

HEADPHONE_EN equ $800000
LINEOUT_EN equ $400000
SPEAKER_EN equ $0040000

MIC_IN_SELECT = mute, 6 dB steps
LEFT_GAIN = 22.6 dB, 1.6 dB steps
RIGHT_GAIN = 22.6 dB, 1.5 dB steps

MONITOR_ATTN = mute, 6 dB steps

OUTPUT_SET equ HEADPHONE_EN+LINEOUT_EN+(LEFT_ATTN*4)
INPUT_SET equ MIC_IN_SELECT+(15+MONITOR_ATTN)+(RIGHT_ATTN*4)
vectors.asm

001 ;
002 page 132,60
003 ;********************************************************************************************
004 ; VECTORS.ASM
005 ; Vector table for the 56303
006 ;
007 ; Copyright (c) MOTOROLA 1996
008 ; Semiconductor Products Sector
009 ; Digital Signal Processing Division
010 ;
011 ;*******************************************************************************************
012 ;
013 ORG P:O
014 ;
015 vectors JMP START ; Hardware RESET
016 ;
017 jmp *
018 NOP ; Stack Error
019 jmp *
020 NOP ;- Debug Request Interrupt
021 jmp *
022 NOP ;- Debug Request Interrupt
023 jmp *
024 NOP
025 jmp *
026 NOP ;- Trap
027 jmp *
028 NOP ;- NMI
029 jmp *
030 NOP
031 NOP
032 NOP ;- Reserved
033 NOP
034 NOP
035 NOP ;- Reserved
036 NOP
037 jmp *
038 jsr main ;- IRQA
039 jmp *
040 jsr echo ;- IRQD
041 jmp *
042 jmp *
043 jmp *
044 jmp *
045 jmp *
046 jmp *
047 jmp *
048 jmp *
049 jmp *
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051 jmp *
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057 jmp *
058 jmp *
059 jmp *
060 jmp *

121
061  NOP  ;= DMA Channel 4
062  
063  jmp  *
064  NOP  ;= DMA Channel 5
065  
066  jmp  *
067  NOP  ;= Timer 0 Compare
068  
069  jmp  *
070  NOP  ;= Timer 0 Overflow
071  
072  jmp  *
073  NOP  ;= Timer 1 Compare
074  
075  jmp  *
076  NOP  ;= Timer 1 Overflow
077  
078  jmp  *
079  NOP  ;= Timer 2 Compare
080  
081  jmp  *
082  NOP  ;= Timer 2 Overflow
083  
084  jsr  ssi_rx_isr  ;= ESSI0 Receive Data
085  
086  jsr  ssi_rx_isr  ;= ESSI0 Receive Data w/ Exception Status
087  
088  jsr  ssi_rxls_isr  ;= ESSI0 Receive last slot
089  
090  jsr  ssi_tx_isr  ;= ESSI0 Transmit Data
091  
092  jsr  ssi_txe_isr  ;= ESSI0 Transmit Data w/ Exception Status
093  
094  jsr  ssi_txls_isr  ;= ESSI0 Transmit last slot
095  
096  NOP  ;= Reserved
097  NOP  
098  NOP  
099  NOP  ;= Reserved
100  NOP  
101  
102  jmp  *
103  NOP  ;= ESSI1 Receive Data
104  
105  jmp  *
106  NOP  ;= ESSI1 Receive Data w/ Exception Status
107  
108  jmp  *
109  NOP  ;= ESSI1 Receive last slot
110  
111  jmp  *
112  NOP  ;= ESSI1 Transmit Data
113  
114  jmp  *
115  NOP  ;= ESSI1 Transmit Data w/ Exception Status
116  
117  jmp  *
118  NOP  ;= ESSI1 Transmit last slot
119  
120  NOP  
121  NOP  ;= Reserved
122  NOP  

122
185 jmp  * ; Available for Host Command
186 NOP  * 
187 jmp  * ; Available for Host Command
188 NOP  * 
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244 NOP  * 
245 jmp  * ; Available for Host Command
246 jmp  *
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<thead>
<tr>
<th>Address</th>
<th>Instruction</th>
<th>Comment</th>
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<tr>
<td>247</td>
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<td>jmp</td>
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<td>308</td>
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</tbody>
</table>
309  NOP    ; Available for Host Command
310  jmp    *
311  NOP    ; Available for Host Command
312  jmp    *
313  NOP    ; Available for Host Command
314  jmp    *
315  NOP    ; Available for Host Command
316  jmp    *
317  NOP    ; Available for Host Command
318 ;
319 ;
intequ.asm

01:***********************************************
02:
03: EQUATES for ONYX 56302 interrupts
04:
05: Last update: June 11 1995
06:
07:***********************************************
08:
09: page 132,56,0,0,0
10: opt mex
11: ineq ident 1,0
12:
13: if @DEF(I_VEC)
14: ;leave user definition as is.
15: else
16: I_VEC equ $0
17: endif
18:
19: ; Non-Maskable interrupts
20: --------------------------------------------
21:
22: !_RESET EQU I_VEC+$00 ; Hardware RESET
23: !_STACK EQU I_VEC+$02 ; Stack Error
24: !_ILL EQU I_VEC+$04 ; Illegal Instruction
25: !_DBG EQU I_VEC+$06 ; Debug Request
26: !_TRAP EQU I_VEC+$08 ; Trap
27: !_NMI EQU I_VEC+$0A ; Non Maskable Interrupt
28:
29:
30: ; Interrupt Request Pins
31: ------------------------------------------
32: I_IRQA EQU I_VEC+$10 ; IRQA
33: I_IRQB EQU I_VEC+$12 ; IRQB
34: I_IRQC EQU I_VEC+$14 ; IRQC
35: I_IRQD EQU I_VEC+$16 ; IRQD
36:
37:
38: ; DMA Interrupts
39: ------------------------------------------
40: I_DMA0 EQU I_VEC+$18 ; DMA Channel 0
41: I_DMA1 EQU I_VEC+$1A ; DMA Channel 1
42: I_DMA2 EQU I_VEC+$1C ; DMA Channel 2
43: I_DMA3 EQU I_VEC+$1E ; DMA Channel 3
44: I_DMA4 EQU I_VEC+$20 ; DMA Channel 4
45: I_DMA5 EQU I_VEC+$22 ; DMA Channel 5
46:
47:
48: ; Timer Interrupts
49: ------------------------------------------
50: I_TIM0C EQU I_VEC+$24 ; TIMER 0 compare
51: I_TIM0SF EQU I_VEC+$26 ; TIMER 0 overflow
52: I_TIM1C EQU I_VEC+$28 ; TIMER 1 compare
53: I_TIM1OF EQU I_VEC+$2A ; TIMER 1 overflow
54: I_TIM2C EQU I_VEC+$2C ; TIMER 2 compare
55: I_TIM2OF EQU I_VEC+$2E ; TIMER 2 overflow
56:
57:
58: ; ESSI Interrupts
59: ------------------------------------------
60: I_SIORD EQU I_VEC+$30 ; ESSI0 Receive Data

127
I_SIORD EQU I_VEC+$32 ; ESSI0 Receive Data With Exception Status
I_SIORS LS EQU I_VEC+$34 ; ESSI0 Receive last slot
I_SIOTD EQU I_VEC+$36 ; ESSI0 Transmit data
I_SIOTDE EQU I_VEC+$38 ; ESSI0 Transmit Data With Exception Status
I_SIOTLS EQU I_VEC+$3A ; ESSI0 Transmit last slot
I_SI1RD EQU I_VEC+$40 ; ESSI1 Receive Data
I_SI1RDE EQU I_VEC+$42 ; ESSI1 Receive Data With Exception Status
I_SI1RLS EQU I_VEC+$44 ; ESSI1 Receive last slot
I_SI1TD EQU I_VEC+$46 ; ESSI1 Transmit data
I_SI1TDE EQU I_VEC+$48 ; ESSI1 Transmit Data With Exception Status
I_SI1TLS EQU I_VEC+$4A ; ESSI1 Transmit last slot

SCI Interrupts

I_SCIRD EQU I_VEC+$50 ; SCI Receive Data
I_SCIRDE EQU I_VEC+$52 ; SCI Receive Data With Exception Status
I_SCITD EQU I_VEC+$54 ; SCI Transmit Data
I_SI1L EQU I_VEC+$56 ; SCI Idle Line
I_SCITM EQU I_VEC+$58 ; SCI Timer

Host Interrupts

I_HRDF EQU I_VEC+$60 ; Host Receive Data Full
I_HTDE EQU I_VEC+$62 ; Host Transmit Data Empty
I_HC EQU I_VEC+$64 ; Default Host Command

Interrupt Ending Address

I_INTEND EQU I_VEC+$FF ; last address of interrupt vector space

LIST
sincos.asm

01 ;
02 ; This program originally available on the Motorola DSP bulletin board.
03 ; It is provided under a DISCLAIMER OF WARRANTY available from
04 ; Motorola DSP Operation, 6501 Wm. Cannon Drive W., Austin, Tx., 78735.
05 ;
06 ; Sine-Cosine Table Generator for FFTs.
07 ;
08 ; Last Update 25 Nov 86  Version 1.2
09 ;
10 sincos macro points,coef
11 sincos ident 1,2
12 ;
13 ; sincos -  macro to generate sine and cosine coefficient
14 ; lookup tables for Decimation in Time FFT
15 ;
16 ;
17 ; points -  number of points (2 - 32768, power of 2)
18 ;
19 ;
20 ;
21 ;
22 ; Latest revision - 25-Nov-86
23 ;
24 ;
25 pi   equ   3.141592654
26 freq equ   2.0*pi/Gcvf(points)
27 ;
28 org   x:coef
29 count set 0
30 dup   points/2
31 dc    -Gcos(Gcvf(count)*freq)
32 count set count+1
33 endm  
34 
35 org   y:coef
36 count set 0
37 dup   points/2
38 dc    -Gsin(Gcvf(count)*freq)
39 count set count+1
40 endm  
41 
42 endm ;end of sincos macro
ADA_INIT.ASM

Example program to initialize the CS4215

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Digital Signal Processing Division

History:
14 June 1996: RLR/LJD - ver.1.0

PLEASE NOTE: For use with rev 2.1 code.

initialize the CS4216 codec

PROGRAM OUTLINE:
1 program fsync and sclk == output
2 write pc0 = 0 (control mode)
3 send 64 bit frame x times, with dcb bit = 0, keep doing until read back as 0
4 send 64 bit frame x times, with dcb bit = 1, keep doing until read back as 1
5 re-program fsync and sclk == input
6 write pc0 = 1 (data mode)
7 receive/send data (echo slots 1,2,3,4; slots 5,6,7,8 == constants)

initialize ssi -- fsync and sclk => outputs

org p:
ada_init
movep #00000,x:M_PCR
; turn off ESSIO port (for now)
movem #103807,x:M_CRA0
; 40MHz/16 = 2.5MHz SCLK, WL=16 bits, 4W/F
movem #ff313C,x:M_CRBO
; RIE,TIE,RLIE,TLIE,RE,TE,sc2/sck outputs
movem #00003,x:M_FRAC
; setup pd0 and pd1 as gpio output
movem #0,x:M_FDCR
; send out a 0 on DC" and RST_CODEC"

;;;; reset delay for codec ----
do #1000,.delay_loop
rep #2000 ; 100 us delay (assuming 40MHz VCD)
bset \$0,x:M_PDRC ; sends out a 1 on pD0 (rst_codec=1)
movep \$0008,x:M_IPRP ; set interrupt priority level for ESSIO to 1
andi \$FC,mr ; enable interrupts

+++++++++++++++++++++++

The following data sets up the CS4215 control mode data:

CTS = Control Time Slot, U/LN = upper/lower Nibble

+------ CTS1-UN: 0 0 1 MLB 0 0 0 0
070 |<------ CTS1-LN: CLB CLB X X 0 0 0 0
071 \|<----- CTS2-UN: HPF X DFR2 DFR1 0 0 1 0
072 \|<----- CTS2-LN: DFR0 ST DF1 DFO 1 1 0 0
073 ; x0 = \$002Cxx
074 ;
075 |<------ CTS3-UN: ITS MCK2 MCK1 MCK0 1 0 0 0
076 |<------ CTS3-LN: BSEL1 BSEL0 XCLK XEN 1 0 0 0
077 \|<----- CTS4-UN: TEST TEST TEST TEST TEST (TEST MUST BE 0)
078 \|<----- CTS4-LN: TEST TEST ENL DAD 0 0 0 0
079 ; x0 = \$8800xx
080 ;

set up buffer with control mode data

081 --- setup buffer with control mode data
082 move CTRL_WD_12,x0
083 move x0,x:TX_BUFF_BASE
084 move CTRL_WD_34,x0
085 move x0,x:TX_BUFF_BASE+1
086 move CTRL_WD_56,x0
087 move x0,x:TX_BUFF_BASE+2
088 move CTRL_WD_78,x0
089 move x0,x:TX_BUFF_BASE+3
090 movep \$003C,x:M_PCRC ; turn on ESSIO except for sc0 and sc2
091
092
093 ; CLB = 0
094 ;
095 ;
096 ;
097 jclr \$3,x:M_SSISRO,* ; wait until rx frame bit==1
098 jset \$3,x:M_SSISRO,* ; wait until rx frame bit==0
099 jclr \$3,x:M_SSISRO,* ; wait until rx frame bit==1
100 jset \$18,x:RX_BUFF_BASE,* ; loop until CLB set
101
102 ;
103 ; CLB == 1
104 ;
105 bset \$18,x:TX_BUFF_BASE ; set CLB
106 do \#_init_loopB
107 jclr \$2,x:M_SSISRO,* ; wait until tx frame bit==1
108 jset \$2,x:M_SSISRO,* ; wait until tx frame bit==0
109 _init_loopB
110 movep \$0000,x:M_PCRC ; disable ESSIO
111
112 ;

now CLB should be 1 -- re-program fsync and sclk direction (i/p) -- also,
circular buffer pointers for echoing data r0=current, r1=old data to send
1 frame later
113 ;
114 ;
115 ;
116 ;
117 movep \$103807,x:M_CRA0 ; 40MHz/16 = 2.5MHz SCLK, WL=16 bits, 4W/F
118 movep \$FF310C,x:M_CRBO ; sc0d and fsync (sc02) as inputs
119 movep \$0003,x:M_PDRC ; D/C pin = 1 => data mode
120 movep \$003C,x:M_PCRC ; turn on ESSIO except for sc0 and sc2
121 rt
Example program to handle interrupts through the 56303 SSIO to move audio through the CS4215

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upon entry:
R6 must be the stack pointer
corrupts:
R6

History:
14 June 1996: RLR/LJD - ver 1.0

;------the actual interrupt service routines (ISRs) follow:

;************************ SSI TRANSMIT ISR ************************
ssi_txe_isr
bclr $4,x:M_SSISRO ; Read SSISR to clear exception flag
; explicitly clears underrun flag
ssi_tx_isr
move r0,x:(r6)+ ; Save r0 to the stack.
move m0,x:(r6)+ ; Save m0 to the stack.
move #3,m0 ; Modulus 4 buffer.
move x:TX_PTR,r0 ; Load the pointer to the tx buffer.
nop
move x:(r0)+,x:M_TXO0 ; SSI transfer data register.
move r0,x:TX_PTR ; Update tx buffer pointer.
move x:-(r6),m0 ; Restore m0.
move x:-(r6),r0 ; Restore r0.
rti

;************************ SSI TRANSMIT LAST SLOT ISR ************************
ssi_txls_isr
move r0,x:(r6)+ ; Save r0 to the stack.
move #TX_BUFF_BASE,r0 ; Reset pointer.
move r0,x:TX_PTR ; Reset tx buffer pointer just in case it was corrupted.
move x:-(r6),r0 ; Restore r0.
rti

;************************ SSI RECEIVE ISR ************************
ssi_rxe_isr
bclr $5,x:M_SSISRO ; Read SSISR to clear exception flag
; explicitly clears overrun flag
ssi_rx_isr
move r0,x:(r6)+ ; Save r0 to the stack.
move m0,x:(r6)+ ; Save m0 to the stack.
move #3,m0 ; Module 4 buffer.
move x:RX_PTR,r0 ; Load the pointer to the rx buffer.
nop
move x:M_RX0,x:(r0)+ ; Read out received data to buffer.
move r0,x:RX_PTR ; Update rx buffer pointer.
move x:-(r6),m0 ; Restore m0.
move x:-(r6),r0 ; Restore r0.
rti
;******************** SSI receive last slot ISR ********************

ssi_rxls_isr

move r0,x:(r6)+ ; Save r0 to the stack.
move #RX_BUFF_BASE,r0 ; Reset rx buffer pointer just in case it was corrupted.
move r0,x:RX_PTR ; Update rx buffer pointer.
move x:-(r6),r0 ; Restore r0.
rti
References


