

# **DOPPLER SHIFTED SPREAD SPECTRUM CARRIER RECOVERY USING REAL-TIME DSP TECHNIQUES**

**Bradley J. Scaife**

**Faculty Advisor: Phillip L. De Leon**

**New Mexico State University**

**Manuel Lujan Center for Space Telemetry and Telecommunications**

## **ABSTRACT**

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 paper, 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 a simple, averaged discrete Fourier transform along with peak detection. We provide 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.

## **KEY WORDS**

Frequency estimation, Doppler shifted carrier recovery, fast fourier transform, spread spectrum.

## **1. INTRODUCTION**

The purpose of this work is to provide a means by which a spread-spectrum, binary-phase shift keying (BPSK) carrier, having undergone an unknown Doppler shift, can be quickly and accurately estimated. The system described herein is to be utilized to implement New

Mexico State University's (NMSU) proposed demand assignment, multiple access (DAMA) service on the existing Tracking and Data Relay Satellite System (TDRSS) [1]. Currently, the ground station receiver (GSR) can perform demodulation given the Doppler shift to within  $\pm 3$  kHz. As the proposed DAMA carrier has been shown to have a theoretical shift of  $\pm 64$  kHz and the state vector of the satellite is not known a priori, it is required to provide the GSR with a locking signal that meets the  $\pm 3$  kHz requirement [1]. This accuracy requirement can be met provided that the processing gain, defined as the ratio of chip rate to data rate (phase changes per bit), of the signal is low enough to exhibit a distinguishable spectral peak above the noise floor [2]. The proposed DAMA service will employ a spread spectrum (SS) communication scheme with such a low processing gain. As the processing gain increases, so does the bandwidth of the mainlobe of the carrier, while the magnitude of the mainlobe is suppressed. In typical SS applications this property is desired, however in the case of the DAMA project it presents the fundamental problem we would like to address, namely, how and under what conditions may we estimate the carrier against the noise floor.

One solution to this problem is to calculate and search for the largest averaged spectral component from which we may base an estimate of the carrier frequency. To this end, we employ an averaged Hamming windowed Fast Fourier Transform (FFT) to generate magnitude-squared data. We can then search the periodogram to detect the peak, from which we generate a locking signal. Averaging is used to increase the accuracy of the estimation by diminishing the effect of noise and other MA users – we would like to avoid basing the estimation on a single iteration of the FFT. Thus, we base our carrier estimation on the averaged periodogram [3]

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

where  $P$  = the number of iterations

$N$  = the number of points of the FFT

$d$  = number of samples dropped between calculations

$\omega$  = radian frequency

$n$  = sample index.

The use of the Hamming window suppresses sidelobes by 40 dB to prevent estimation error; the noisy environment could otherwise produce an unacceptable estimation error by picking out a sidelobe coupled with additional spectral energy instead of the mainlobe [4]. Finally the FFT is used since it is computationally efficient. Simulation results in Section 2 verify accuracy and justify this method.

The method described above is implemented in digital hardware using an 80MHz Motorola DSP56303EVM (303EVM) evaluation board and a Burr Brown ADS7810/19C

12 bit 800kHz analog-to-digital converter (ADS7810). The 303EVM contains a codec which will be used to generate the locking signal to the GSR. As it is an audio band codec operating at 32kHz, the locking signal generated will require additional hardware to frequency multiply it up to an equivalent 800kHz sampling rate. The DAMA signal is to have a mainlobe bandwidth of 200kHz and will be bandpass filtered and frequency shifted to baseband. With a theoretical maximum Doppler shift of  $\pm 64$ kHz, the frequency estimation will occur over a 328 kHz range [5]. The ADS7810 was chosen since it operates at a sample frequency of 800kHz, covering a 400kHz range, and is a commonly available, inexpensive part.

## 2. BACKGROUND THEORY AND SIMULATION RESULTS

We now provide simulation results to verify the accuracy and tolerance of the periodogram method described above. The simulations were run under the following parameters:

- Carrier Frequency,  $f_c = 164$ kHz
- Doppler Shift = 32kHz
- Data Rate = 1Kbps
- Chip Rate = 10Kbps
- Processing Gain = 10
- Number of FFT iterations = 8
- Length of FFT = 512 points

The carrier frequency of 164kHz chosen is typical of a DAMA signal and a Doppler shift of 32kHz was chosen arbitrarily though within the  $\pm 64$ kHz range. Additionally, we have chosen to perform eight iterations with which to average and have implemented a length 512 FFT. The FFT bin width is as shown in (2-1).

$$\Delta f = \frac{f_s}{L} = \frac{800kHz}{512} = 1.563kHz \quad (2-1)$$

where  $f_s$  = sampling rate

$\Delta f$  = FFT bin width

$L$  = FFT length

The results of the simulation are shown in Fig. 1 where we plot the proportion of frequency estimates within the  $\pm 3$ kHz range versus a signal-to-noise ratio (SNR) range of  $-10$  dB to 4 dB for a SS BPSK carrier. In the range of our simulation we demonstrate accuracy ranging from 0.86 to 0.91.

### 3. SOFTWARE AND HARDWARE DESCRIPTION

We now consider implementation of the real-time algorithm developed to perform the carrier estimation. The 303EVM utilizes a dual data memory (X, Y) architecture. The memory scheme that we run under provides 2kB program memory, 3kB X memory, and 3kB Y memory. The algorithm's memory usage is described below:

- 682 bytes of program memory.
- 2048 bytes of L memory (concatenation of X and Y).
- 540 bytes of X memory.
- 512 bytes of Y memory.

There is an additional 32kbytes-memory off-chip that is not used. We make use of look-up tables (precalculated values stored in memory) to keep computational overhead to a minimum. To further reduce computational complexity, we pre-scale the Hamming window coefficients by  $1/P$ , where  $P$  is the number of iterations that we will perform. We can then simply add the magnitude-squared data of our FFT through each iteration to average. Upon completion of the final FFT, we begin a sequential search through the frequency bins to determine the largest magnitude-squared component. Since the input is real, the DFT is conjugate symmetric. Thus we need only search the first 256 points of the FFT. The functional flowchart for the algorithm is shown in Fig. 2 below.

The computational cost of the algorithm is now considered. Of relevance is only the time to locking tone generation, indeed, the buffering of samples is not even computationally expensive as the processor is simply waiting for the next sample to be taken. As such, initialization and locking tone generation is not considered. Only the time from sample buffer full to tone generation is relevant to computational cost discussion. The cost analysis is provided in Table 1.

**Table 1: Computational Costs**

<b>Subroutine</b>	<b># of Instructions</b>	<b>Time</b>	<b>Total Time</b>
Window and Scale	512	6.4 $\mu$ s	6.4 $\mu$ s
FFT [5]	4105	51.313 $\mu$ s	57.713 $\mu$ s
Average FFT (squared data)	512	6.4 $\mu$ s	64.113 $\mu$ s
		x iterations (8)	0.5129 ms

The 303EVM, produced by Motorola, is an advanced DSP specific processor that operates at 80 million instructions per second. With the advanced pipelining architecture, instructions are executed in one clock cycle [6]. This part is extremely versatile and low cost. In addition, as discussed above, a part capable of higher sampling rates was required for the A/D conversion. The part chosen was a ADS7810 which has a sampling rate of 800kHz. An interface board was required in order to address the BB into the memory

map of the 303. The input to the processor then is sampled at 800kHz and the output utilizes the 32kHz audio codec that is on board. The locking signal is required to be frequency shifted by a multiple of 25.

#### **4. CONCLUSIONS**

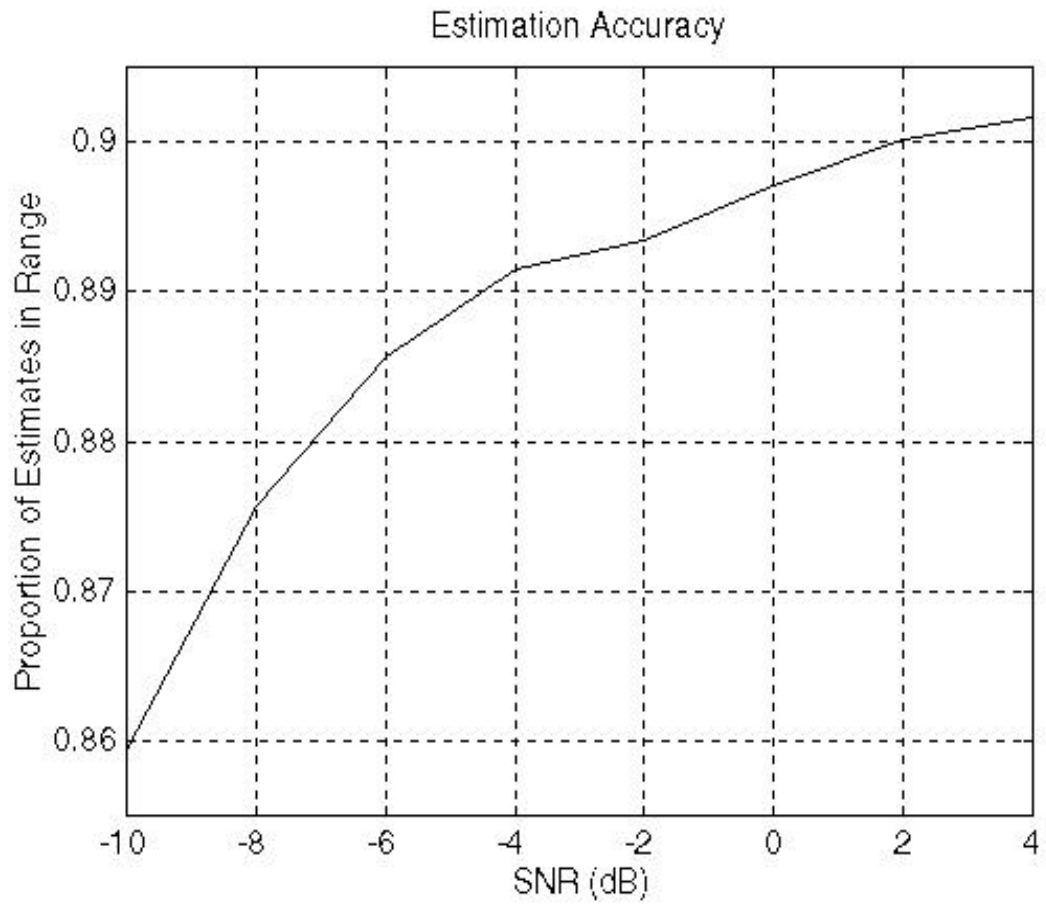
This paper has shown one method to accurately find a spread-spectrum, binary-phase shift keying modulated carrier that *has* undergone an unknown Doppler shift provided that it has a low processing gain. We have implemented the method using low-cost DSP-based hardware for real-time operation.

#### **5. ACKNOWLEDGMENTS**

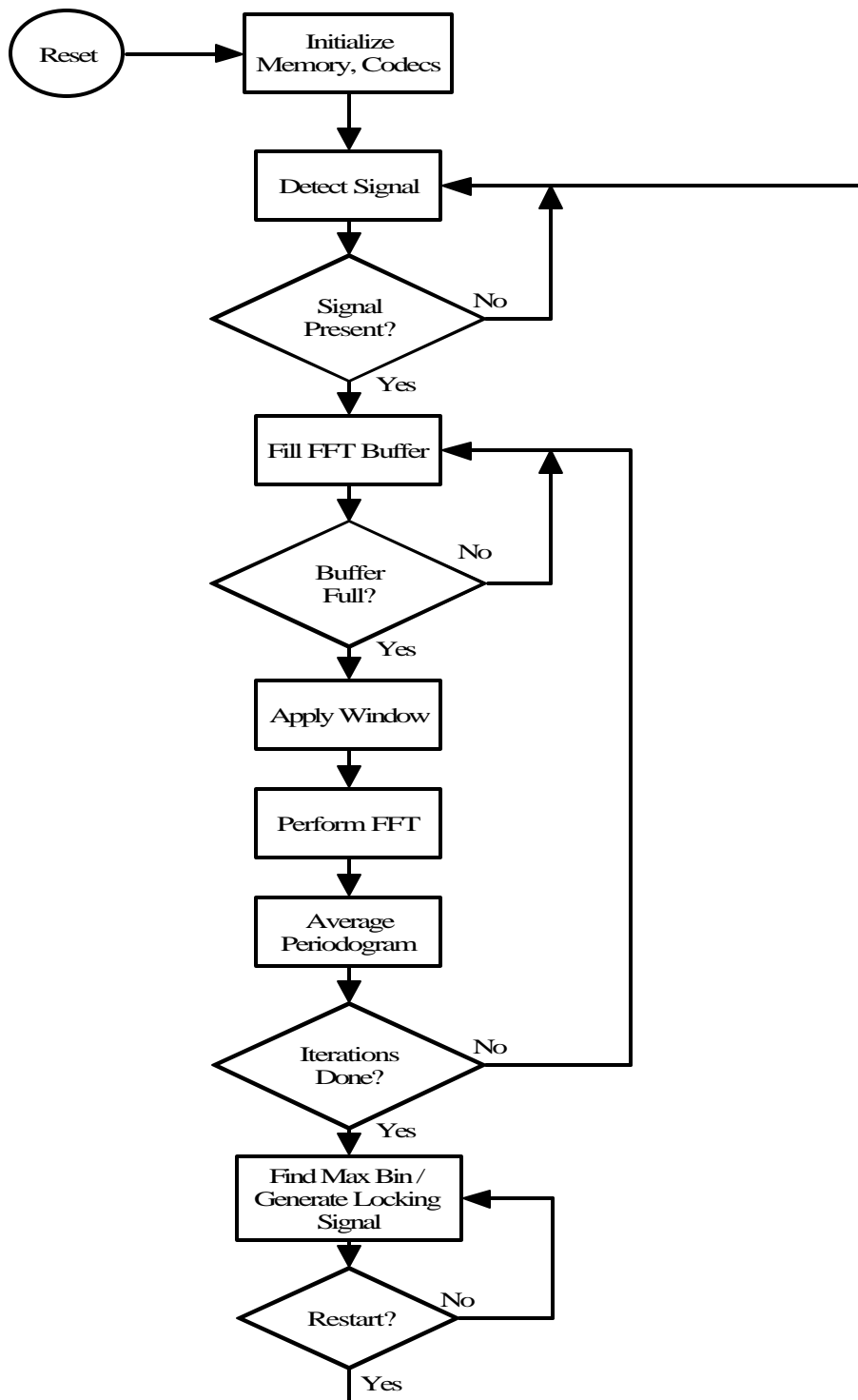
The authors wish to thank Tim Bagget for design of an interface card between the A/D and the 303EVM and for additional hardware and software suggestions.

#### **6. REFERENCES**

- [1] M. Sanchez, "Doppler Extraction for a Demand Assignment Multiple Access Service for NASA's Space Network," *Proceedings International Telemetry Conference*.
- [2] P. Flikkema, "Spread-Spectrum Techniques for Wireless Communication", *Signal Processing Magazine*, IEEE, Vol. 14, NO. 3, May 1997.
- [3] B. Porat, *A Course in Digital Signal Processing*, John Wiley & Sons, Inc., 1997.
- [4] S. Orfanidis, *Introduction to Signal Processing*, Prentice-Hall, 1996.
- [5] P. De Leon, "Real-Time DSP-Based Carrier Recovery with Unknown Doppler Shift," *1997 International Conference on Signal Processing Applications & Technologies* (San Diego, CA.), 1997.
- [6] Motorola, *DSP56300 Family Manual*.



**FIGURE ONE: ESTIMATION ACCURACY OVER SNR RANGE (10000 estimates per SNR)**



**FIGURE TWO: FUNCTIONAL FLOWCHART OF CARRIER ESTIMATION ALGORITHM**