A High Speed Data Acquisition and Processing System for Oscillatory Experiments

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ABSTRACT

A data acquisition and processing system has been especially designed for accurate determination of amplitudes and relative phasing of periodically time varying steady state signals whoose signal-to-noise ratio is very low. The maximum sampling frequency is 1 MHz and 10^9 data points can be acquired without interruption.

INTRODUCTION

Many experiments, such as measurement of dynamic viscoelasticity, oscillatory flow birefringence, oscillatory electric birefringence, and dielectricity, involve the measurement of the response of a sample to a periodic excitation. The success of the experiment depends critically on the ability to extract precise amplitudes and relative phasing of the excitation and response signals. For experiments on dilute solutions these signals are often weak and the signal-to-noise ratio is very low.

An improved version of a data acqusition and processing system for such signals has been designed. The system consists of commercially available hardware and custom designed software.

SYSTEM DESIGN

The hardware components of the system are:

- two frequency synthesizers with 1μHz resolution driven from one master reference oscillator (stability of 2 parts in 10^9 per week) for synchronization (Hewlett Packard Model 3325A)
- a Macintosh II computer with at least three NuBus expansion slots
- a data acquisition board with four channels and a maximum aggregate sampling rate of 1 MHz (National Instruments NB-A2000)
- a digital signal processing board (National Instruments NB-DSP2300)
- a GPIB interface board to allow the Macintosh to control the synthesizers (National Instruments NB-GPIB)

A schematic diagram of the system is shown in Fig. 1. The overall data acquisition process is controlled by the Macintosh computer. It instructs one of the synthesizers to generate the drive signal for the instrument and the other to generate the sampling clock for the data acquisition board. It also initializes the data acquisition board, downloads a program to the digital signal processing board and transfers control to it. During the actual data acquisition the Macintosh is idle. Both the drive and response signals are digitized by the data acquisition board and the digitized data are transferred to the digital signal processor. A DMA controller on this board frees the CPU from the burden of data transfer and thus enhances the ability of the system to perform real-time calculations. Two types of averaging[1] are employed to suppress the effect of noise and reduce the amount of memory needed to store the data. When data acquisition is complete, the averaged data are transferred to the Macintosh for further analysis.

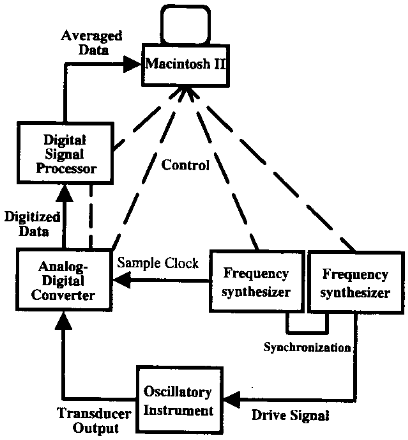

Figure 1. A schematic diagram of control and information flow in the data and acquisition and processing system.

Programs for the Macintosh and the digital signal processing board have been written in assembler and C.

DATA ANALYSIS

The digitized, averaged signals are cross-correlated against references of the known input frequency - or its harmonics if nonlinear effects are of interst - to extract amplitudes and relative phasing of the signals. Careful selection[1] of the number of signal cycles sampled allows the system to act as a tunable filter and reject almost any frequency which may be known to enter the system as noise (line voltage pick up, mechanical transducer resonances, etc.). All harmonics are rejected completely. If k signal cycles are sampled, k-1 evenly spaced frequencies between each pair of harmonics are also rejected completely.

FREQUENCY RANGE

The frequency response of the analog electronics part of the data acquisition board was determined by sending a clean signal into all four channels and recording the amplitudes and phases relative to the signal recorded for channel 0. The result is seen in Fig. 2. Unfortunately, we were unable to obtain a sufficiently precise independent measure of the synthesizer output voltage for frequencies above 10 kHz.

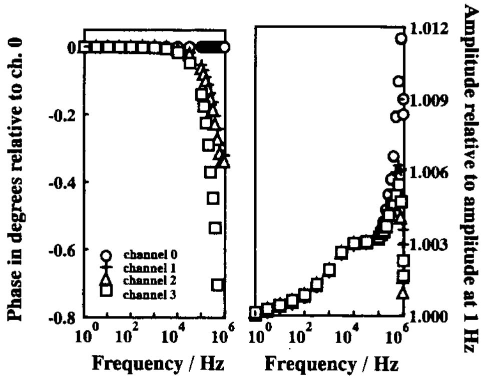

Figure 2. Frequency response of the system presented as the phase difference relative to channel 0 (left) and the amplitudes of each channel, normalized to the amplitude at 1 Hz (right).

The usuable frequency range becomes somewhat smaller when aliasing signals may be present as noise. According to the Nyquist theorem, the sampling frequency must be more than twice the highest frequency present in the signal to resolve the individual frequency components in the signal. When sampling 1, 2 or 4 channels the Nyquist frequencies are 0.5 MHz, 0.25 MHz and 0.125 MHz, respectively.

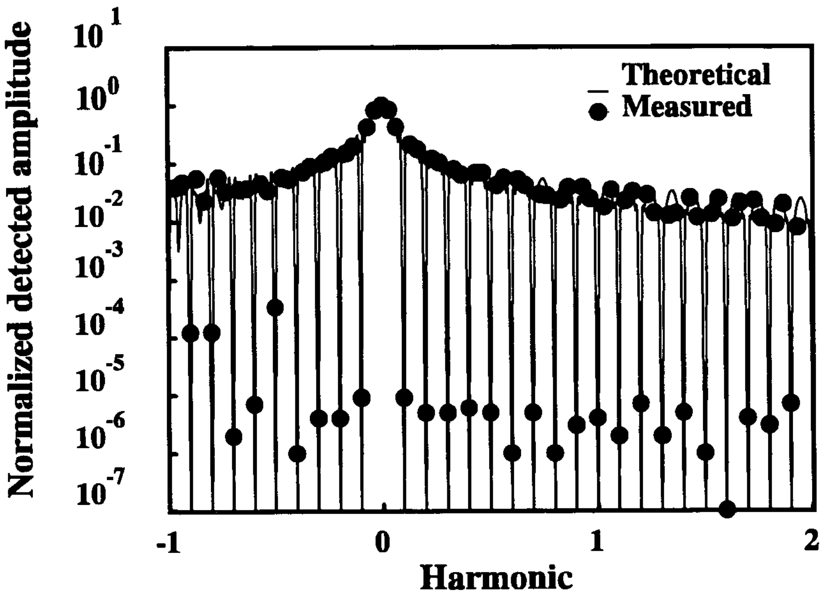

Figure 3. Measured and theoretical fractions of the amplitude of the signal that is detected by the system. The system is looking for a fundamental frequency, i.e. the 0th harmonic, but is fed signals of different frequencies. The detected amplitude normalized to the true amplitude is 1 for the fundamental frequency, corresponding to no rejection. For each harmonic and for 10-1=9 evenly spaced frequencies between each pair of harmonics, the detected amplitudes are about five orders of magnitude smaller than the true amplitude of the signal, corresponding to almost complete rejection.

REJECTION OF FREQUENCIES PRESENT AS NOISE

To demonstrate the ability to reject unwanted periodic signals, the system was fed signals with frequencies other than the one the system was looking for. The fraction of the amplitude for different frequencies that is detected by the system is shown in Fig. 3 where 10 signal cycles were sampled.

Correspondence between the measured and theoretical[1] rejection is good. The amplitude of the unwanted signal is reduced considerably, and for signals of frequencies which are theoretically predicted to be completely rejected, the amplitude is reduced by five orders of magnitude.

CONCLUSION

Commercially available hardware has been interfaced using custom designed software to produce a data acquisition and processing system which achieves high sampling rate, extended averaging times and excellent phase precision. The system presents a potent tool for the precise characterization of periodic signals of known frequency under extremely noisy conditions. In particular, the potential to tune the system to reject periodic "noise" signals of any desired frequency is valuable in many instrumental applications.

REFERENCES

1. G. Winther, D. M. Parsons and J.L. Schrag, "A High Speed, High Precision Data Acquisition and Processing System for Experiments Producing Steady-State Periodic Signals", submitted to Journal of Polymer Science.