ON RESPONSE MEASUREMENTS USING DETERMINISTIC TYPES OF PERIODIC SIGNAL AND FFT

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1. Introduction

System response measurements appear in many areas of scientific and technical investigations. The speed of these measurements has been greatly improved with the advent of FFT analyzers. Conventional FFT analyzers require two channels to measure the system response using white noise as a stimulus. Bias errors such as aliasing, leakage, and picket fence effects have to be properly addressed and random errors have to be minimized by averaging. Uses of deterministic types of periodic signal as stimulus are not common although most of these errors would disappear. The inflexibility of the commercial FFT analyzers may be an important reason. To analyze periodic signals, it is necessary to use an 'exact' multiple of the period of the signal to avoid leakage effect. It is also necessary to ensure that the signal frequencies coincide 'exactly' with the analysis frequencies to avoid picket fence effect. This will require some tailoring of the sampling frequency and the number of data points. In this paper, we will explore the application of deterministic types of periodic signal for system response measurements using a dual channel A/D converter and a special FFT routine. Two types of periodic signal will be discussed: (1) pure tones for single frequency measurements and (2) m-sequence or maximum-length sequence (MLS) for broad-band measurements.

2. Pure-tone Tests

This is a simple signal to use for system response measurements. Usually, the magnitude is measured with a ratio meter and the phase with a phase meter. More accurate results can be obtained using a lock-in amplifier. Chu[1] has used such a technique for impedance tube measurements based on the two point transfer-function technique. Since the lock-in amplifier is not a common laboratory instrument, an alternative way of measurement using the FFT has been considered. Figure 1 shows the arrangement of equipment for checking the accuracy of the proposed method. Pure tones of different frequencies (125, 250, 500, 1000, 2000, 4000 Hz) were generated by a stable function generator (HP 3325A). A 12 bit dual-channel A/D converter was used to sample simultaneously both the input and output signals of the linear system under test. The sampling frequency used was 10 kHz and the number of data points chosen was 2000. This combination satisfied the two conditions mentioned in Section 1. To perform the discrete Fourier transform on 2000 points, a special non-power of 2 FFT routine is required. Two routines are available; one is the Chirp Z transform[2] and the other is the Glassman's general n points FFT[3]. The latter was used in this study. Table 1 shows the phase response of a digital delay system (Klark-Teknik DN700) at different delay settings. The average and sigma were obtained from 20 repeated measurements. The measured results compare very well with the calculated results from the delay settings.

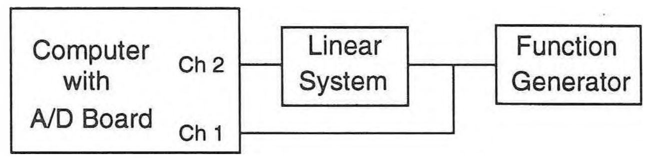

Figure 1. Diagram of equipment used in pure-tone tests.

Frequency	125	250	500	1000	2000	4000
0.0265ms delay	-1.19	-2.38	-4.77	-9.54	-19.08	-38.16
Measured<Phase>°	-1.19	-2.39	-4.77	-9.55	-19.11	-38.18
Sigma (deg)	0.006	0.007	0.009	0.011	0.021	0.018
0.053ms delay	-2.38	-4.77	-9.54	-19.08	-38.16	-76.32
Measured<Phase>°	-2.38	-4.77	-9.54	-19.09	-38.22	-76.33
Sigma (deg)	0.005	0.008	0.008	0.012	0.017	0.014
0.0795ms delay	-3.58	-7.16	-14.31	-28.62	-57.24	-114.48
Measured<Phase>°	-3.58	-7.16	-14.31	-28.64	-57.32	-114.46
Sigma (deg)	0.006	0.007	0.008	0.017	0.011	0.015

Table I. Comparison of the expected phase response of a digital delay system with measurements using pure-tones. Averages and sigma were computed from 20 repeated measurements.

3. m-Sequence Tests

An m-sequence is a periodic binary sequence generated by digital shift registers with appropriate feedback[4]. The most important property of any m-sequence is that its circular autocorrelation function is essentially an

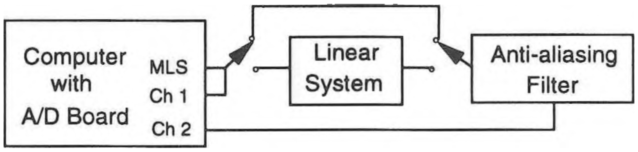

Figure 2. Diagram of equipment used in m-sequence tests.

impulse. This property immediately suggests that the impulse response of linear systems can be measured by cross-correlating the system output with the m-sequence excitation signal[5]. The periodic length, L, of the m-sequence is always one less than an integer power of 2. Special technique is available to calculate the impulse response[6,7]. Frequency response can also be determined directly using the general n points FFT routines mentioned in the previous section. Since the m-sequence is periodic, one can use an exact multiple number of periods to eliminate the leakage effect. Using the same clock frequency for both the m-sequence generation and the sampling frequency of the A/D converter will ensure that the analysis frequencies coincide exactly with those of the m-sequence. An anti-aliasing filter is required for accurate measurements, whose response has to be determined and corrected for in the computation of the unknown system response. Figure 2 shows a schematic diagram of the equipment set-up. An m-sequence of 4095 points was used with a clock frequency of 10 kHz. The impulse response of the system was determined first and the frequency response was obtained by Fourier transforming the impulse response. Figure 3 shows the average phase response of a 3 kHz low-pass filter and the standard deviation obtained from 10 repeated runs as a function of frequency. Values at 125, 250, 500, 1000, 2000, 4000 Hz were picked and compared with those obtained using pure-tones. Table II shows good comparison for both magnitude and phase except for the phase result at 4 kHz obtained by the m-sequence method. Better agreement was obtained for this case when the sampling frequency was increased to 16 kHz.

4. Conclusion

We have shown that accurate response measurements can be made using periodic signals and FFT. With proper choice of the sampling frequency and the number of data points, bias errors associated with FFT can be eliminated. Random errors become insignificant because the periodic signals used are deterministic.

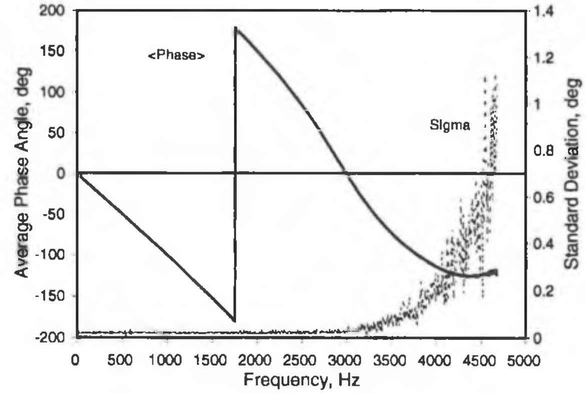

Figure 3. Average and standard deviation of the phase response of a 3 kHz low-pass filter from 10 measurements.

Frequency	125	250	500	1000	2000	4000
			<Magnitude >dB			
Pure-tone						
Average	0.07	0.05	0.03	-0.01	-0.12	-20.36
Sigma	0.001	0.000	0.001	0.001	0.001	0.002
MLS:10k SF						
Average	0.07	0.06	0.04	-0.00	-0.12	-20.33
Sigma	0.003	0.002	0.004	0.004	0.002	0.026
MLS:16k SF						
Average	0.07	0.06	0.05	0.00	-0.13	-20.21
Sigma	0.004	0.003	0.004	0.004	0.003	0.018
			<Phase>deg			
Pure-tone						
Average	-12.44	-24.73	-49.40	-99.60	151.52	-118.46
Sigma	0.002	0.003	0.003	0.005	0.010	0.013
MLS:10k SF						
Average	-12.45	-24.76	-49.42	-99.63	151.59	***-113.59***
Sigma	0.024	0.019	0.023	0.020	0.017	0.178
MLS:16k SF						
Average	-12.44	-24.79	-49.45	-99.66	151.54	-118.66
Sigma	0.028	0.015	0.031	0.023	0.021	0.103

Table II. Comparison of the frequency responses of a 3 kHz low-pass filter measured with pure-tones and with the m-sequence using different sampling frequencies (SF).

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