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# On-Demand MEMS Accelerometer Dynamic Response Acquisition and  Output Dithering via Self Test Pin Actuation.

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*Abstract*—**Any sensor or system employed to measure a physical property will by default impart some alteration to the original signal due to its inherent non-perfect response. Knowing the relationship between the input and the output of such a sensor or system is therefore essential for the correct definition of the original signal measured. What is presented herein is an experimental investigation of determining a MEMS accelerometer's dynamic characteristics by repurposing the self test pin made available by the manufacturer for simple binary functionality test. The Analog Devices ADXL325 was used for all the experiments described in this document.**

*Keywords—MEMS accelerometer; self test pin; dynamic response*

## I. INTRODUCTION

Although the static or steady state performance of a system is incredibly important for accuracy and long term performance, when dealing with fast changing signals, the dynamic response of a system is of vital importance to the quality of the data acquired.

Since the acquisition of a sensor's dynamic response is typically achieved by tests conducted on a vibration platform able to sweep across frequencies in the bandwidth of interest, an on-demand acquisition of a sensor's dynamic and static response in the field for the purpose of calibration is therefore very challenging. Extensive work has been done to address the issue of self-calibration on-chip, comprising silicon, algorithmic and stimuli architectures [1- 4], however, the cost-sensitive nature of most MEMS accelerometers generally dictates that commercially available accelerometers are only equipped with a single test pin. This test pin simply provides a binary operational test to the user, as upon the application of a voltage to the pin, an electrostatic force is exerted onto the internal inertial mass, forcing it to deflect, thus producing a voltage output on all sensing axes. The utilization of this pin for the purpose of derivation of dynamic characteristics has not been keenly explored in previous work, other than to partially quantify on-chip self test architectures based on complex pseudorandom stimuli [5]. The work presented herein however, demonstrates direct stimulation methods for the acquisition of reliable sensor dynamic response via impulse and frequency sweep excitation, and also extends the work into the acquisition of better quality data via self test pin stimulation for output dithering, without the requirement of complex external, or any additional on-chip circuitry.

## II. SENSOR FREQUENCY RESPONSE BY SWEEP-FREQUENCY EXCITATION

The test pin on the ADXL325 was experimentally found to be internally buffered, possessing a threshold voltage a little below 2V; a strategy possibly employed to deliver a predictable response and avoid interference due to external spurious noise. The excitation of the inertial mass via the test pin by the application of a square wave of amplitude greater than the threshold, at incremental frequencies was explored for the acquisition of the sensor's frequency response. The resulting output responses of different sensors tested between DC and 6 KHz followed a typical mass-spring characteristic curve (Fig. 1) with the addition of an atypical dip between the frequencies of 1.5 KHz and 3 KHz. The otherwise compliant frequency response acquired by the excitation of the self test pin confirmed that the internal interfacing electronics of the test pin do not limit the frequency of the input signal below the sensor's operational limit of 1.6 KHz as specified by the manufacturer.

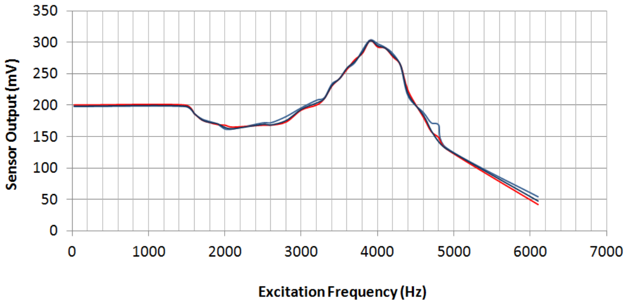

Fig. 1. Frequency response via square wave frequency sweep on test pin.

From the experimental results of Fig. 1, a flat response from DC to 1.5 KHz is evident, followed by a characteristic resonant peak at 3.9 KHz. These findings are very close to the manufacturer's stated useful flat bandwidth response of DC to 1.6 KHz, and a peak resonance at 5.5 KHz. Presented with the above experimental findings, Analog Devices has since confirmed that the internal conditioning electronics produce filtering of the output presenting a -3dB at 1.6 KHz low pass characteristic, thus confirming the validity of the experimentally derived response, by explaining both the observed uncharacteristic dip, and the shift of the mechanical resonance peak to a lower frequency, as a combined electromechanical effect. In a real in-field application, drifts in dynamic performance can be feasibly and easily quantified on-demand using the sweep-frequency method, by acquiring and averaging sweep-frequency output data.

## III. SENSOR OUTPUT DITHERING VIA HIGH FREQUENCY EXCITATION

Excitation of the self test pin with square waves at much higher frequencies than the sensor's resonant frequency showed that forcing the inertial mass to oscillate at these higher frequencies resulted in a generally unstable behaviour, but with the output still remaining within the typical amplitude characteristic of Fig. 1. At a frequency of 6.1 KHz however, the inertial mass was found to regain stability, with the sensor output exhibiting a sinusoidal voltage of amplitude 54 mV peak-to-peak, and a mean DC offset of -86mV from the nominal no excitation (zero-g) baseline. As such, whilst powered from a 3V supply and at a position orthogonal to the gravitational field, direct measurement of the sensor's zero-g voltage output presented a value of 1.526V (a value within tolerance of the typical half the supply voltage level expected). A mean DC level of 1.440V was subsequently witnessed upon the application of a 3V, 6.1 KHz square wave input signal to the test pin.

Since any mechanical excitation of the sensor can be thought of as a superimposition on the electrostatically induced 6.1 KHz signal, the 6.1 KHz signal could be successfully utilised as a form of dithering at the expense of some dynamic range reduction.

The superimposing effect of the test pin generated dithering on a mechanically induced vibration signal, can be seen in Fig. 2 and Fig. 3, depicting a mechanically induced vibration with and without the dithering signal employed respectively.

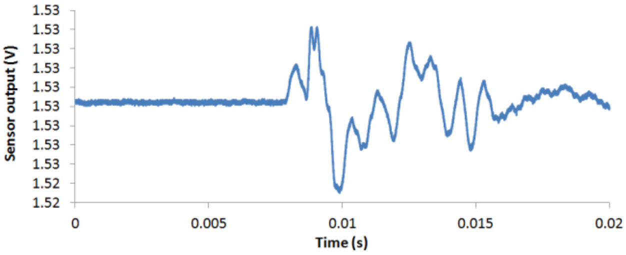

Fig. 2. Sensor output of mechanical vibration only.

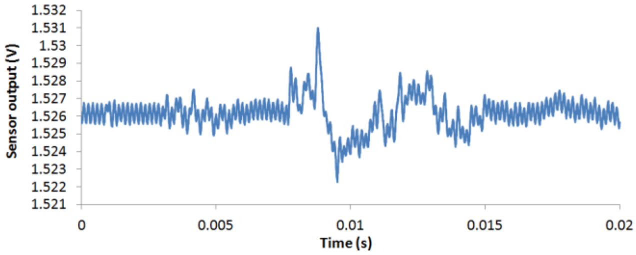

Fig. 3. Sensor output of mechanical vibration and dithering on test pin.

Such means of dithering can provide substantial benefits especially in the capturing of the very low frequency, low amplitude undulations, present in many applications such as seismography and breath analysis, provided that the loss in dynamic range is acceptable for the intended application.

## IV. SENSOR DYNAMIC RESPONSE VIA IMPULSE EXCITATION

It was envisaged, that an impulse response representing the characteristic behaviour of the sensor could be derived, if excitation of the test pin was delivered via a narrow voltage pulse, approximating an impulse with respect to the general sensor dynamic characteristic.

It is widely accepted that any linear system, or a system within its linear range of operation, can be thought of as having an output y(n) equal to the convolution of its input x(n) and its impulse response h(n) such that

$$y(n) = h(n) \circledast x(n) \tag{1}$$

Having acquired the sensor's output y(k) as a result of an unknown input signal x(k), the ability to acquire the impulse response h(k) of the sensor on-demand, should provide the ability to numerical derive the original minimally distorted signal x(k). Although the requirement for de-convolution can present a challenge for a solution targeting minimal circuit complexity, it can be dealt with much more directly in the frequency domain. Using the Fast Fourier Transform (FFT) to convert both the sensor's impulse response and its output data in the frequency domain, represented as H[K] and Y[K] respectively, de-convolution can then be performed by the simple division

$$\frac{Y[K]}{H[K]} \tag{2}$$

Subsequent application of the inverse FFT (IFFT) on the quotient in (2) should result in the reconstruction a minimally distorted input signal x(k).

In order to practically investigate the feasibility of original signal recovery using impulse de-convolution, a low-pass filter was added to the output of the sensor restricting the bandwidth to 5 KHz, thus providing a predefined known dynamic sensor-filter characteristic. The application of a 20µs pulse of 3V in amplitude as an impulse stimulus to the test pin resulted in an impulse response output characteristic depicted in Fig. 4.

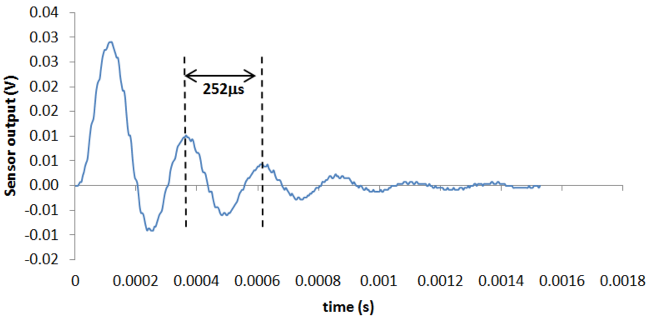

Fig. 4. Sensor output of impulse input on test pin.

As evident in Fig. 4, the measured resonance period of 252µs, and therefore a frequency of 3.96 KHz, confirms the validity of the result as it is in satisfactory agreement with the resonant frequency derived in the earlier frequency sweep experiment. Further system evaluation can be obtained if needed by the derivation of the step response by the numerical integration of the impulse response, as depicted in Fig. 5.

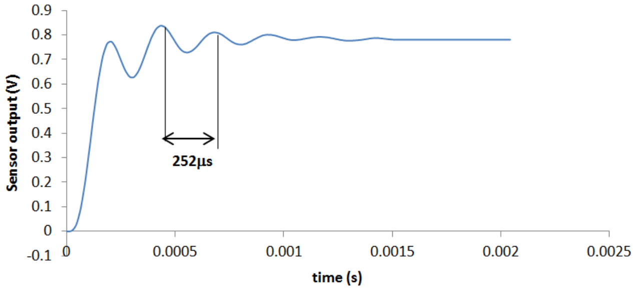

Fig. 5. Sensor step response derived by impulse response integration.

A sinusoid of frequency 1.5 KHz, and therefore within the sensor's 5KHz filter bandwidth, intentionally corrupted by an out of band 7.5 KHz noise sinusoid of a lesser amplitude (Fig. 6), was synthesized to serve as a test input.

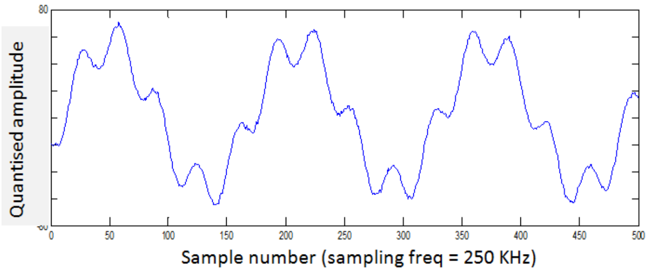

Fig. 6. Digitally synthesized test input.

Convolution of the synthesised input with the experimentally derived filtered sensor's impulse response, yielded an output in whch the high frequency 7.5 KHz noise component lying just outside the 5KHz bandwidth, was highly attenuated whilst the fundamental frequency sinusoid was mainly retained with only partial evidence of noise remaining (Fig. 7). This result is in agreement with the expected performance of the sensor-filter arrangement, considering that the noise frequency is relatively close to the -3dB cut-off point of the filter.

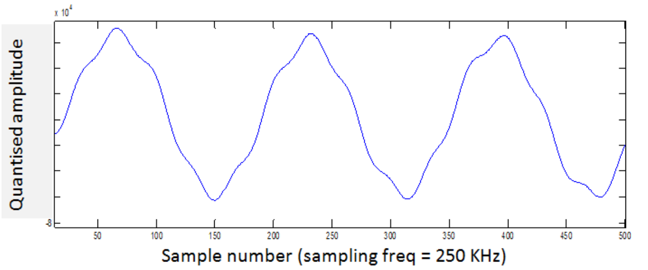

Fig. 7. Convolved output of test input with sensor impulse response.

The results of Fig.7, in conjunction with the frequency sweep results, provide strong evidence in support of the suitability of impulse response acquisition for the purpose of dynamic sensor acquisition via impulse excitation of the self test pin on MEMS accelerometer devices.

## V. CONCLUSION

The results from this study convincingly indicate the suitability of the self test pin, present on many MEMS accelerometers, to be utilised for the acquisition of the dynamic response of such sensors. The ability to acquire a sensor's dynamic response in situ, on demand, and without complex external circuitry, dictates that in part at least, the validity of sensor data can be guaranteed over long term in a realistic field placement situation. Further, the utilization of the self test pin as means of providing dithering to the sensor's output data was also shown to be achievable, potentially resulting in much increased data accuracy in terms of quantization, especially in applications where slow, lower frequency signals are of importance.

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