Comparison of Capacitive and Feedback-Interferometric Measurements on MEMS

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Abstract—In this paper, we consider a typical microelectromechanical structure consisting of a small mass suspended by four laminar springs, which can be forced to vibrate by electrical actuation, and represents the basic block of many accelerometers, gyroscopes and resonators. Measurements of parameters, such as the actuation efficiency, the resonance frequency and the quality factor, have been performed for such device by feedback interferometry, and the results are compared with data obtained by the standard capacitive method.

Index Terms—Mechanical variables measurement, microsensors, microelectromechanical systems (MEMS), micromachining, optical interferometry.

I. INTRODUCTION

The micromachining technology provides a wide range of sensors [1], [2] for industrial and consumer applications, and is suitable for mass production at low cost. Characterization and diagnostics of such microelectromechanical systems (MEMS) often require an accurate determination of displacement, speed, vibration amplitude and other mechanical quantities. In this paper, we present an optical inspection method, based on feedback interferometry, which is suitable for fast and accurate characterization of vibrating micromachined devices, such as accelerometers, gyroscopes and microresonators. The results of the measurements performed by this technique on a typical micromechanical element are compared with experimental data obtained by the capacitive electrical method.

II. THE TESTED DEVICE

The micromechanical structure that we consider in this paper is reported in Fig. 1, and consists of a laminar mass suspended in the horizontal plane by four laminar springs. This arrangement, even though with different aspect ratio, is the basic block of several micromechanical devices, such as accelerometers [3], [4], gyroscopes [5], microresonators [6]. To actuate the device, and/or to detect its vibration amplitude, some tens of capacitors are built along the sides of the moving mass, so that one plate of each capacitor is attached to the frame around the device and the other to the mass. Two basic arrangements are possible: “parallel-plates” [3], as in Fig. 1, where the movement is orthogonal to the plates (i.e., along the y-axis), and “comb-fingers” [6]–[8], where the movement is parallel to the plates.

In resonators and gyroscopes, the mass is forced to vibrate along the driving axis (y-axis in Fig. 1) by an electrostatic force, which is generated by applying a periodic voltage \( V_o + v_o \sin(2\pi f_o t) \) to one or both capacitor combs. The same driving method is often used for the preliminary characterization of accelerometers, before the direct mechanical testing.

For design optimization, it is often required to monitor the resonance frequency \( f_r \) and the quality factor \( Q \) of the mechanical system (or even to measure its whole frequency response), as functions of the applied sinusoidal and dc voltages \( v_o \) and \( V_o \), as well as of external parameters, such as pressure. These measurements are aimed, for example, at implementing the functional matching of the driving and sensing resonances of a gyro, or to determine the required vacuum level for efficient operation. From the resonance curves one can also identify nonlinear or parasitic phenomena, such as hysteresis of the mass displacement, or the excitation of undesired vibration modes. Another important parameter is the actuation efficiency \( \zeta \), defined as the ratio of the peak-to-peak amplitude of the mass displacement \( S \) (at resonance) to the peak-to-peak amplitude of the applied sinusoidal voltage \( 2v_o \).

The typical electrical readout scheme for capacitive sensors represents a method to perform such measurement. The driving...
signal is applied to one capacitor array of the axis under measure (e.g., the left comb in Fig. 1) while the other (the right comb in Fig. 1) is used to transduce the mass vibration. The varying capacitance of such comb is included in a voltage divider, which is fed by a high-frequency (1–10 MHz) carrier \( V_C \). Due to the mass inertia, the carrier does not contribute to vibration. However, the signal at the output of the divider, read by a high-impedance amplifier, contains the frequency-translated, amplified response of the device to the driving waveform; thus the resonance curve can be measured simply by frequency-sweeping the driving signal.

Alternatively, as explained in [6] and shown in Fig. 2(a), \( V_C \) can be applied between the moving mass and the electrical ground. In this case, a signal equivalent to that of the previous scheme is supplied by a transimpedance amplifier connected to the output comb.

While they represent a viable solution to implement on chip the readout of a device, these electrical schemes are not always suitable for the characterization of a bare sensor, where parasitic phenomena play a major role. As a matter of fact, the stray capacitance of the connecting wires and of the external front-end can be an order of magnitude higher than the whole capacitance of the combs (typically, 0.1–0.5 pF), and can often mask the sensor response. Also, with some devices, a large spurious beating between the driving signal and the carrier may be observed at the output. Finally, it should be noted that gyros and other devices, which are designed to be driven on both combs, cannot be measured in standard operating conditions by such technique.

To tackle these problems, many authors have proposed optical methods, based, for example, on image processing or diffused light analysis [9]–[11] to perform a direct noninvasive measurement of the mass movement.

As it is well known, interferometry offers the best accuracy and resolution among optical methods. Unfortunately, classical interferometric schemes are difficult to apply to MEMS characterization for different reasons. First, the vertical sidewalls of the mass (in the planes \( xz \) and \( yz \)) are hidden by the case and/or silicon frame and cannot be easily reached by a laser beam. Second, the mass does not represent a good optical surface, since it is rough, and holed to remove the underlying sacrificial layer. Finally, the setup should allow measurements inside a vacuum chamber, since it is often required to determine \( Q \) as a function of pressure.

An efficient solution is provided by feedback interferometry, which, as we show in the following, represents an important tool for the characterization of MEMS.

III. THE OPTICAL MEASUREMENT METHODS

Feedback interferometry [12]–[14] is an interesting alternative to the classical interferometric techniques. Its main advantage is that it requires neither external optics (other than a collimator and/or a focusing lens), nor accurate alignment and wavefront matching. Also, it has no reference arm, and thus it can be implemented by a simple and compact setup.

Our experimental arrangement is shown in Fig. 2(b). The device under test was positioned inside a glass vacuum chamber, on a suitable holder, at an angle \( \alpha = 20^\circ \) with respect to the laser beam. The laser/target distance was of about 30 cm.

Feedback interferometry is based on the amplitude and frequency modulations arising on the laser oscillation, when a small fraction \( W_f \) of the power \( W_o \), emitted by the source, is diffused (or reflected) by the target and is injected back into the laser itself.

As it is well-known, backreflection from a mirror into a laser source can lead to a variety of regimes, including compound cavity effects, self-modulation and even chaos and coherence collapse [15], [16]. However, in our setup the radiation which is collected by the laser cavity is small enough to prevent instability. On the other hand, when working orthogonally to the surface, and/or with a reflective target, it may be necessary to reduce the injected power by an attenuator (or by slightly defocusing the beam) to keep the source within the so-called moderate injection regime \( (W_f/W_o < 10^{-5}) \), which is suitable for interferometric measurements.

In such conditions, as explained in [13], the current output signal from the monitor photodiode at the rear mirror of the laser [see Fig. 2(b)] has the form

\[
I = I_o + I_{\text{max}} \cos(\Omega_f \tau), \tag{1}
\]

In this equation, \( I_o \) is proportional to \( W_o \), \( I_{\text{max}} \) is proportional to \( (W_o W_f)^{1/2} \), \( \tau \) is the round-trip time in the external cavity (defined by the laser output mirror and the target), and \( \Omega_f \) is the angular frequency of the laser with the external cavity.

In the weak injection regime [12], [17], which is observed with the low-level backward signal provided by our target \( (W_f/W_o \approx 10^{-6}) \), \( \Omega_f \) is virtually equal to the unperturbed laser pulsation \( \Omega_o = 2\pi c/\lambda \), where \( \lambda \) is the laser wavelength, and \( c \) is the speed of light. Thus, the expression of the photodetected current \( I \) can be simplified to

\[
I = I_o + I_{\text{max}} \cos \left( \frac{4\pi}{\lambda} (s(\tau) + s_o) \right) \tag{2}
\]
where $s(t)$ is the component of the target displacement along the direction of the laser beam and $s_0$ is the target distance at rest. It follows that for weak injection the target displacement relative to $s_0$ can be obtained simply by fringe counting, i.e., by detecting the zero-crossings of the interferometric signal $I(t) = L$. Namely, if the number of fringes within a half period of the forcing waveform is $M$, the peak-to-peak amplitude of the vibration of the target is

$$S = M \left( \frac{\lambda}{2} \right) \left( \frac{1}{\cos \alpha} \right). \quad (3)$$

The resonance curve of the mechanical system can therefore be obtained by measuring the displacement amplitude for different frequency values of the driving signal.

An advantage of this approach is its intrinsic immunity to alignment fluctuations, which affect only the signal amplitude and not the zero-crossings. Depending on the operator experience, the minimum vibration amplitude which can be detected by direct observation at an oscilloscope is 0.5–1 fringe (which typically corresponds to 0.2–0.5 μm), with a resolution of a fraction of a fringe.

On the other hand, the maximum amplitude is limited by the frequency response of the front-end transresistance amplifier, since the fundamental frequency of the interferometric signal is approximately $2Mf_r$.

The accuracy and sensitivity of this technique, as of any other interferometric scheme, depend on the setup stability (which is better achieved with a low component-count), on the source power, and on the intensity of the signal from the target, which on its turn depends on the working angle and on the optical characteristics of the target itself.

With respect to Michelson’s, a feedback interferometer has virtually the same output signal for the same power budget [18]; however, the spatial filtering action provided by the laser cavity on the injected radiation offers a better signal-to-noise ratio (SNR) when the signal waveform is distorted, such as for operation on a diffusive target. Spatial filtering can be obviously implemented also in a Michelson’s scheme, but this would result in a rather critical setup. A calculation of the signal amplitude and of the SNR for feedback interferometry has been reported in [19].

The setup shown in Fig. 2(b) measures the vibration along the beam axis. By using multiple beams, or by making different measurements at different beam orientations, it is possible to reconstruct the oscillation amplitude on three orthogonal axes, thus obtaining a full characterization of the target movement. These measurements will not be reported for the structure of Fig. 1, where the oscillation amplitude along axes other than the $y$-axis is very small. However, such characterization is interesting for more complex structures, such as a dual-mass gyro.

Modifications of the basic excitation and readout scheme can be also considered.

A possibility is to use white noise as the varying component of the driving signal instead of a sinusoid. As it is well known, feeding a linear system by white noise is equivalent to sweeping the frequency of a sinusoidal input [20], and thus the (amplitude) resonance curve can be visualized directly by an electrical spectrum analyzer reading the photodetected signal. In such measurement, care must be taken so as to operate in linear conditions, in spite of the cosine dependence of the interferometric signal (2). This can be obtained by selecting a suitable value of $s_0$ (i.e., of $V_o$) corresponding to a zero-crossing of the cosine function, around which (2) can be linearized, provided that the noise amplitude is small. In practice, to validate the measurement, the operator has to check that the electrical response, observed at the spectrum analyzer, is free of spurious resonances at harmonics of $f_r$.

As compared to fringe-counting, the white noise method is easier and faster, and it is suitable for measuring small movements (well below a single fringe), as often required with MEMS.

Unfortunately, since the output signal directly scales with the optical power, calibration is necessary to measure the true vibration amplitude, as required for example to derive parameter $\zeta$. On the other side, white noise allows for an accurate measurement of $Q$ and $f_r$, provided that the setup is mechanically stable during the measuring time. In practice, when working on a vibration-isolated optical table, the operating point is stable enough to allow signal integration for at least one minute. This has been verified by observing the stability of the fringes obtained by a sinusoidal signal, after trimming the setup for maximum output. It is worth noting that a moderate fluctuation of the operating point, around the cosine zero-crossing, results in a reduction of the amplitude of the output signal, which does not affect the measurement of $Q$ and $f_r$.

A third option to consider, at least in principle, is the optical measurement of the step response of the system, which, for a (minimum phase delay) linear system, provides the same information as frequency sweeping. For our second-order system, the expected response is a damped sinusoid at the resonance frequency $f_r$, whose envelope has an exponential decay of time constant $\tau_c = 2\pi Q/f_r$.

This method can be implemented, in practice, by applying a low-frequency square wave to the input instead of a sinusoid. If the period of the waveform is long with respect to $\tau_c$, the step response can be directly observed by an oscilloscope to measure $Q$ and $f_r$. Usually, however, direct observation in the time domain cannot be accurate, because the applied signal is small (well below a fringe), as required to work in linear conditions, and a spectral measurement is thus preferable.

By straightforward calculations using the Fourier transform, it can be shown that the response of the mechanical system to a (small) square wave has the form

$$K(j2\pi f) = -\psi_s \left[ t_0 \exp(j2\pi ft_o) \sin \left( \frac{2\pi ft_o}{T} \right) \right] \times \left[ \frac{2\pi}{T} \sum_n \delta \left( \frac{2\pi f - 2\pi n}{T} \right) \right]$$

(4)

where

$\psi_s$ and $T$ amplitude and period of the square wave, respectively;
$t_o$ duration of the upper level;
$\sum_n \delta(.)$ comb of $\delta$-pulses;
$H(j2\pi f)$ transfer function of the mechanical system.
If $H(j2\pi f)$ has a relatively narrow bandpass response, as it usually happens with resonant structures, it can be visualized at the spectrum analyzer by a suitable choice of $t_e$ and $T$. Namely, the distortion due to the $\sin(t)$ function in (4) can be minimized by making its lobes much larger than $H(j2\pi f)$, and by placing its zeros so that $H(j2\pi f)$ is at the center of one of such lobes. On the other hand, the sampling effect due to the $\delta$-comb becomes negligible if the bandwidth of $H(j2\pi f)$ is much larger than $1/T$.

It is evident from these considerations that the step-response method requires a more involved trimming procedure with respect to the sinusoidal and white-noise excitation; moreover, its accuracy is lower, and in practice it can provide just a rough estimate of $f_c$ and $Q$. As white-noise excitation, it is not suitable for a direct measurement of the vibration amplitude without calibration.

A more detailed comparison between the different methods will be made in the next paragraph, where we will present experimental data.

In the above discussion, we have implicitly assumed that the sinusoidal or square wave voltage resulted into an applied force of the same form on the mass. As a matter of fact, however, both parallel-plate and comb-finger drivings exhibit a quadratic dependence of the force on the applied voltage [7], [8]. This problem, which is common to both the electrical and the optical approach, has been tackled in all measurements reported in the following (as in most applications), by meeting the condition $v_o \ll V_o$ so as to ensure first-order linear operation.

A similar consideration applies to the electrical measurement of the (parallel-plate) output capacity $C$ [8], which has a quadratic dependence on the mass displacement.

**IV. THE MEASUREMENT SETUP**

The optical measurements were performed by using a Hitachi 7851G infrared laser diode at $\lambda = 785$ nm emission wavelength. Working at this wavelength helps in the alignment procedure, because the laser spot can be seen with the naked eye. This source was selected because it exhibits a stable single-mode spectrum under different injection conditions; it was operated at about half its maximum output power (50 mW).

In the following, we report on the measurements we have performed on a $700 \times 100 - \mu m$ parallel-plate accelerometer fabricated by surface micromachining with epitaxial growth (thickness $15 - \mu m$). By the same technique we have tested also vibrating gyros and resonators as well as other MEMS structures, such as torsional gyros.

It is interesting to observe that an optical grade window is not required for the vacuum chamber. Indeed, our experiments were made through a standard glass bell-jar, simply by focussing or collimating the beam on the target, and avoiding to work orthogonally to the glass surface to reduce disturbing reflections.

The spatial resolution of the setup depends on the diameter of the laser spot on the target, which can be of the order of $1 \mu m$, as with standard interferometers. Unfortunately, when working through a vacuum bell-jar, the spot dimension is somewhat increased by the wavefront distortion due to the glass. Nevertheless, submicron resolution can be achieved when one measures a moving part of the target. In fact, as already stated, a vibration of the target at frequency $f_c$, generates a signal at frequency $2Mf_c$,

which can be easily separated by electronic filtering from the contributions due to fixed (or slowly moving) parts at (or near) dc.

Indeed, by the optical methods, we have been able to measure not only the mass displacement, but also the movement of the springs of our device, which are about $0.3-\mu m$ thick. Moreover, by accurately focussing the beam, it has been possible to measure devices which were partially covered by bonding wires, whose practical effect was just to reduce the amplitude of the interferometric signal. It is worth noting that the capacitive method does not allow to perform measurements on different points of the structure, but only to detect the vibration of the whole mass.

The electrical measurements were performed by the scheme of Fig. 2(a) [6]. Since this method does not directly measure the mass displacement, the actuation efficiency $\zeta$ has been calculated as a function of the experiment parameters, obtaining

$$\zeta = \frac{V}{(Rf_c Vc_0 A N v_{t_{0}})} \left[ \frac{2(D - y_{c})^2}{y_{c}^2 D^2 - 2Dy_{c}} \right].$$

In this expression, $f_c$ is the carrier frequency, $V$ is the amplitude of the sideband at $f_c + f_{o}$, $V_{c_0}$ is the carrier amplitude, $A$ is the surface of each capacitor plate, $y_{c}$ is the distance between the plates at rest, $N$ is the number of capacitors, $D$ the pitch of the comb (Fig. 1). Parameter $R$ is the feedback resistance of the op-amp [see Fig. 2(a)].

**V. EXPERIMENTAL RESULTS**

A typical measured plot of the varying component of $I(t)$ is shown in Fig. 3 (upper trace); the driving sinusoidal wave (lower trace) is also shown to highlight its timing relatively to the interferometric signal. The maximum displacement in Fig. 3 is of about 2.2 fringes, corresponding to a peak-to-peak vibration amplitude $\Delta \approx 1 \mu m$.

The diagrams of Fig. 3 were taken by a digital oscilloscope, after amplification of $I(t)$ by a standard high-pass transimpedance scheme. By averaging on several (8-64) periods of the driving signal, the effects of the slow ambient vibrations on the mechanical setup were strongly reduced, thus obtaining a good SNR. Fringe visibility (i.e., the modulation depth of the
Fig. 4. (a) Amplitude resonance curve measured at $P = 0.2$ torr by feedback interferometry (dots) and by the standard electrical method (bold gray line). The dotted-dashed line represents a nonresonant spurious term and the dashed curve is the computed electrical response (see text). (b) Phase resonance curve by feedback interferometry. The theoretical (Lorentzian) amplitude and phase curves are also shown (full line).

Photodetected electrical signal before dc filtering) was typically $10^{-5}$ in our setup.

Fig. 4(a) shows the amplitude resonance curve of the accelerometer at low pressure ($P = 0.2$ torr) as measured by fringe counting (dots). This diagram has been drawn using data from graphs such as those of Fig. 3. The matching theoretical Lorentzian curve is also shown (full line). Other curves, relative to data taken by the electrical method, will be discussed later. The phase diagram, obtained by observing the timing of the interferometric signal with respect to the driving signal, is reported in Fig. 4(b). It has been noted that for large driving (i.e., in nonlinear conditions), the amplitude and phase diagrams are not matched: in other words, differently from Fig. 4, the phase corresponding to the resonance peak is not 90°.

A typical resonance curve obtained at the spectrum analyzer in response to a white-noise input is reported in Fig. 5 for another sample of the same device ($P = 0.06$ torr). The input signal was 70 $\mu$Vrms/Hz$^{1/2}$. This plot should be compared with that of Fig. 6, which has been measured by the method of the step response; in the latter, the sampling of the output spectrum is evident, as predicted by (4).

In Figs. 7–10, we present a comparison of the results obtained on the structure of Fig. 1 by the different measuring methods. The values of $V_o$, $v_o$, $V_c$ are reported in each caption. The carrier frequency of the electrical measurement was $f_c = 2$ MHz. All measurements have been performed on the same accelerometer, except from those of Fig. 9, which are pertinent to another sample of the same device.

In Fig. 7 the resonance frequency of the device has been plotted as a function of the dc voltage $V_o$. The dependence of the resonance frequency on $V_o$ is due to the so-called electrostatic stiffness effect, consisting in a variation of the equivalent spring elastic constant $K$ due to the electrostatic force[21]. The white-noise measurements are limited to $V_o = 1$ V, due to the characteristics of our generator; the agreement with electrical measurements and fringe counting is good, though a somewhat different trend can be observed; this was probably due to an incipient degradation of the device, which failed after a short time. However, similar measurements on other MEMS, including accelerometers and gyros, have not shown significant differences between white-noise excitation and the other methods considered in this paper.

Figs. 8 and 9 show the quality factor $Q$ as a function of pressure $P$. Though the measurements have been taken on two different device samples, a comparison between the different schemes is possible, since data on the fringe-counting method are available for both.

Finally, Fig. 10 shows the actuation efficiency $\zeta$ as a function of pressure. It can be observed that the results of the electrical and optical (fringe counting) measurements are significantly different. An explanation will be given below.
Fig. 5. Resonance curve measured by feedback interferometry with white noise excitation (amplitude spectral density: \(70 \mu \text{Vrms}/(\text{Hz})^{1/2}\); dc offset \(V_o = 600 \text{ mV}\)).

Fig. 6. Resonance curve measured by feedback interferometry with step excitation (\(V_o = 500 \text{ mV}, v_x = 1 \text{ V}, \) square wave frequency: 8 Hz).

Data on white noise and step excitation have not been reported in Fig. 10, since these methods are not suitable for performing a measurement of the vibration amplitude without calibration.

From the reported data, it can be concluded that the three different optical readout schemes, considered in this work, when applicable, give consistent results. This had to be expected, since they all are based on feedback interferometry, and thus make a direct measurement of the mass displacement.

As for the electrical method, it can be observed that its agreement with the optical measurements is good for \(f_r\), while discrepancies are found for \(Q\) and \(\zeta\).

As anticipated, this is apparently due to spurious effects which disturb the setup of Fig. 2(a). Indeed, in our experiments, we have observed that the signal sideband at \(f_c + f_o\), visualized by a spectrum analyzer, was superposed to a nonresonant beating term between the driving signal and the carrier, giving a rather large pedestal. This disturbance, probably caused by nonlinear superposition of the two applied waveforms on the silicon structure, could be only partially reduced by electrical screening, and made it difficult to perform measurements especially at low \(Q\), where the response is very smooth.

More important, a significant distortion of the resonance curve was observed. This can be appreciated for example from...
Fig. 7. Resonance frequency as a function of dc voltage $V_o$: optical measurement by fringe counting ($v_o = 150$ mV) and by white noise excitation (amplitude spectral density: $70 \mu$Vrms/(Hz)$^{1/2}$), compared with the standard electrical measurement (carrier amplitude $V_c = 600$ mV).

Fig. 8. Quality factor $Q$ as a function of pressure $P$: optical measurements by fringe counting ($v_o = 150$ mV) and by white noise excitation (amplitude spectral density: $70 \mu$Vrms/(Hz)$^{1/2}$). The dc voltage is $V_o = 600$ mV.

Fig. 4(a), where the electrical response (bold gray line) is significantly different from the ideal Lorentian shape (full line) and from the optically measured curve (dots).

It can be shown that such distortion comes from the superposition between the intrinsic resonance and the spurious beating, which have a frequency-dependent relative phase delay.

Indeed, since the interferometric measurement directly monitors the mass movement, it can be assumed as a good approximation of the intrinsic resonance; thus, the amplitude diagram [dots in Fig. 4(a)] represents the signal that would be observed at the spectrum analyzer in ideal conditions (without disturbance). Moreover, the amplitude of the spurious term can be measured at the spectrum analyzer by working out of resonance [horizontal dashed-dotted line in Fig. 4(a)]; since it is nonresonant, a constant phase value $\phi$ has been assumed for such term. We have then computed the sum of the two contributions. Assuming $\phi = 0$, the two terms sum up in phase far before resonance, they are in quadrature on the resonance peak, and they subtract far after resonance. From this calculation, the dashed line in Fig. 4(a) has been obtained, which indeed matches the electrical experimental curve.
It is interesting to note that this approach correctly predicts the electrically measured resonance curve even in nonlinear conditions, when, as stated above, the intrinsic (optically measured) amplitude and phase curves are not matched.

It is important to point out that while the observed distortion does not greatly affect the peak position (which measures $f_c$), it results into an underestimation of $Q$ at low pressure, as it is evident from Fig. 9. Its effect is even more remarkable in the measurement of $\zeta$ (Fig. 10), which requires an accurate determination of the resonance peak value.

VI. CONCLUSION

Several measurements on different devices have proved that feedback interferometry is a valuable tool for MEMS characterization, since it directly measures the mass displacement, it can work on a diffusing surface and can be implemented by a very simple optical setup. Some results, selected among the most representative and significative ones, have been reported in the previous section.

Feedback interferometry is particularly suitable for bare devices, where the electrical methods suffer from stray capaci-
tance and interference. Another advantage of the interferometric method, as compared to the electrical one, is that only two wires (for the driving signal) have to be connected to the chip and fed through the vacuum bell-jar. More important, no critical cabling to detect the output signal is required. Finally, the optical methods do not require to modify the standard electrical driving of the device.

Among the different optical redouts, it has been verified that the fringe-counting method is especially suitable for relatively large vibrations (at least 1–2 fringes) and, in this case, it performs well even at low (<10) Q-value and provides a direct measurement of the vibration amplitude. The white-noise and the step methods are both more suitable to low-amplitude vibrations (below a fringe). With white-noise excitation, the transfer function of the device is quickly determined by a single measurement. Its accuracy in the measurement of Q is good especially for medium (>10) to high Q values. Also, it allows fast determination of the resonance frequency avoiding a boring research by sweeping, when no theoretical prediction of f₀ is available. Its main drawback is that it does not provide an absolute measurement of the vibration amplitude without calibration. The step method requires a rather involved trimming of the setup parameters and is viable at medium Q values, where the sampling of the output spectrum does not affect the results.

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