Portable Network Analyzers For Full Characterization Of FBAR Sensors: Influence Of Readout Parameters On Sensor Performance

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***Abstract*—The commercial readout electronics of thin film bulk acoustic wave resonators (FBARs) are typically implemented via free-running or phased-locked oscillators. Oscillators cannot provide the user with the full characterization of the sensor. Recently, the tendency of many network analyzer (NA) manufactures is towards miniaturized and less expensive systems. This opens up the possibility of commercializing FBARs coupled to a compact NA readout system. We have assessed how the configuration of the NA (IF bandwidth, acquisition points) directly affects the final performance of an FBAR sensor in terms of acquisition time, limit of detection and final resolution. Additionally, we have also studied how the presence of unwanted spurious modes can affect this sensor performance, despite the use of a fitting algorithm for frequency shift extraction. Acquisition times and limit of detection can be reduced below 100 ms and 0.5 kHz respectively, allowing resolutions in the fg range for our sensors.**

Keywords—FBAR; electroacoustic sensor; network analyzer; fitting; acquisition time; limit of detection; resolution.

I. INTRODUCTION

In the field of acoustic wave sensors (AWS), network analyzers (NAs) have so far been considered as bulky expensive machines needed for laboratory characterization, especially of AWS in the GHz range. The readout electronics of thin film bulk acoustic wave resonators (FBARs) and quartz-crystal microbalances is implemented via free-running or phased-locked oscillators [1]–[3], not a NA. Oscillators indeed offered so far an effective solution in terms of cost and encumberment, although cannot provide the user with the full characterization of the sensor. This is not the case of NAs, which can extract from FBARs information as: resonant or antiresonant peaks, losses, phase variations, electromechanical coupling, etc. In addition to this, NAs enable the measurement of a wider bandwidth, which is especially important when AWS are used as sensors. Recently, the tendency of many NA manufactures is towards miniaturized and less expensive systems (Fig. 1). This opens up the possibility of commercializing AWS coupled to a compact NA readout system.

In this work we discuss the practical possibilities and issues encountered when fully characterizing FBAR gravimetric sensors with a compact NA read-out system. We assess how

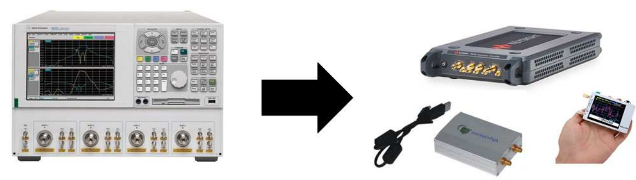

Fig. 1. Example of miniaturization tendency in NAs, from bulky to portable ones [4], [5].

some configuration options (e.g. IF bandwidth and number of points per sweep) of the NA, affect the data extraction of the FBAR response and hence the performance of a gravimetric sensor based on FBARs. The studied performance includes the limit of detection (LoD), the resolution and the acquisition time of an FBAR sensor. Additionally, we also discuss how the quality of the FBAR resonant peaks contributes to the mentioned performance parameters.

II. METHODS

We have measured AlN-based solidly mounted resonators (SMRs) in the 2 – 3 GHz frequency range with a compact NA manufactured by Keysight (P9371A). The SMRs are composed of an acoustic reflector on which we deposit our piezoelectric material sandwiched between two metallic electrodes (Fig. 2).

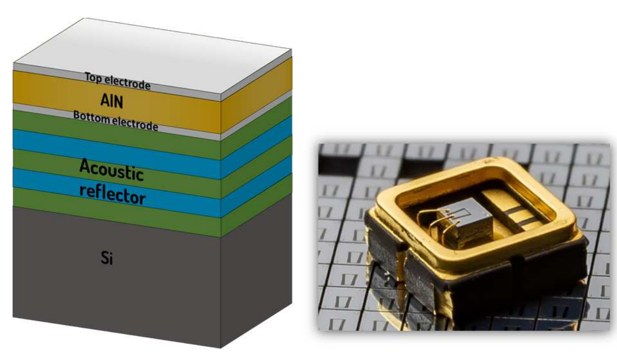

Fig. 2. Structure of an SMR (left) and our final device (700 x700µm) in a 3x3 mm package [6].

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The acoustic reflector is made of alternating layers of high and low acoustic impedance materials and its scope is to prevent acoustic leakage to the Si substrate.

The basic operation of SMRs as gravimetric sensors is based on their frequency shift towards mass deposited on their surface [7]. Generally, the resonant frequency is the one being

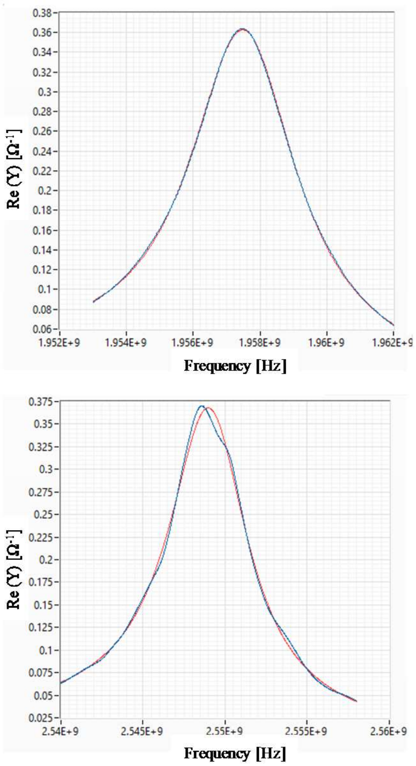

Fig. 3. Two examples of the measured resonant peaks: without spurious modes (top) and with spurious modes (bottom). The blue line is the measured data and the red one is the fitting curve.

tracked. By using a NA we can fit the real part of admittance peak using a specific algorithm, and track with a better accuracy the resonant frequency. Although this fitting can considerably suppress the influence of spurious modes in some peaks, the frequency reading accuracy is still degraded by these unwanted modes. We have studied the resonant frequency readout in two types peaks, with and without spurious modes (Fig. 2). In both cases we have applied the same fitting function.

III. RESULTS AND DISCUSSION

The resonant peaks were measured in a frequency span of 10 – 20 MHz and the influence of two NA parameters was assessed: the IF bandwidth and the number of points per sweep. The influence of all configurations and NA parameters was studied in terms of acquisition time of the frequency values (extracted from the maximum of the fitted ReY peak), limit of detection (LoD), which is directly related to the resulting signal to noise ratio, and the sensor mass resolution based on their previously characterized mass sensitivity.

In Fig. 4a we can see an example of frequency reading from a peak without spurious modes and how the IF bandwidth values of the NA influence the acquisition time for the same number of points. On the other hand, Fig. 4b proves how the number of points influence the data reading while the IF bandwidth is kept the same.

Tables I and II present the extracted values of acquisition times, LoD and mass resolutions for different values of IF bandwidths and number of points, for peaks with and without spurious presence. The mass resolution is directly dependent on the LoD and inversely proportional on the mass sensitivity of the sensor:

$$Resolution = \frac{LoD}{Sensitivity}\ [g]$$

The mass sensitivity of our SMR sensors was previously calculated by sequential depositions of thin film SiO_2 layers, being the extracted value in the order of 1.5 ± 10% [Hz cm^2/pg]. By taking this sensitivity value and considering a device active area of around 38500 μm^2, we can estimate the mass resolutions presented in Table I and II.

From Fig. 4a and both Tables we can observe how the lower the IF bandwidth, the lower the LoD, hence improved resolution. The same happens with the number of points, as we can see from Fig. 3b. The greater the number of points the better the resolution. For both cases, IF bandwidth and number of points, increasing their value translates to better resolutions but higher acquisition times. For example, for 10000 points we can get acquisition times of 20 s.

As for the influence of the spurious presence, we can see from Tale II how these unwanted peaks distort the readout accuracy of our sensor and worsen the values of all three readout parameters. This occurs despite the fitting technique and would be even worse if a fitting method would not be employed.

TABLE I. RESONANT PEAK WITHOUT SPURIOUS PRESENCE

IF [kHz]	Points	Acquisition time[s]	LoD [kHz]	Resolution [pg]
1	2000	0.3	0.2	0.05
1	500	0.1	0.3	0.08
30	2000	0.25	1.5	0.39
30	500	0.08-0.1	3	0.78

TABLE II. RESONANT PEAK WITH SPURIOUS PRESENCE

IF [kHz]	Points	Acquisition time[s]	LoD [kHz]	Resolution [pg]
1	1000	3	6	1.55
1	500	1	7	1.81
30	500	0.5	10	2.59

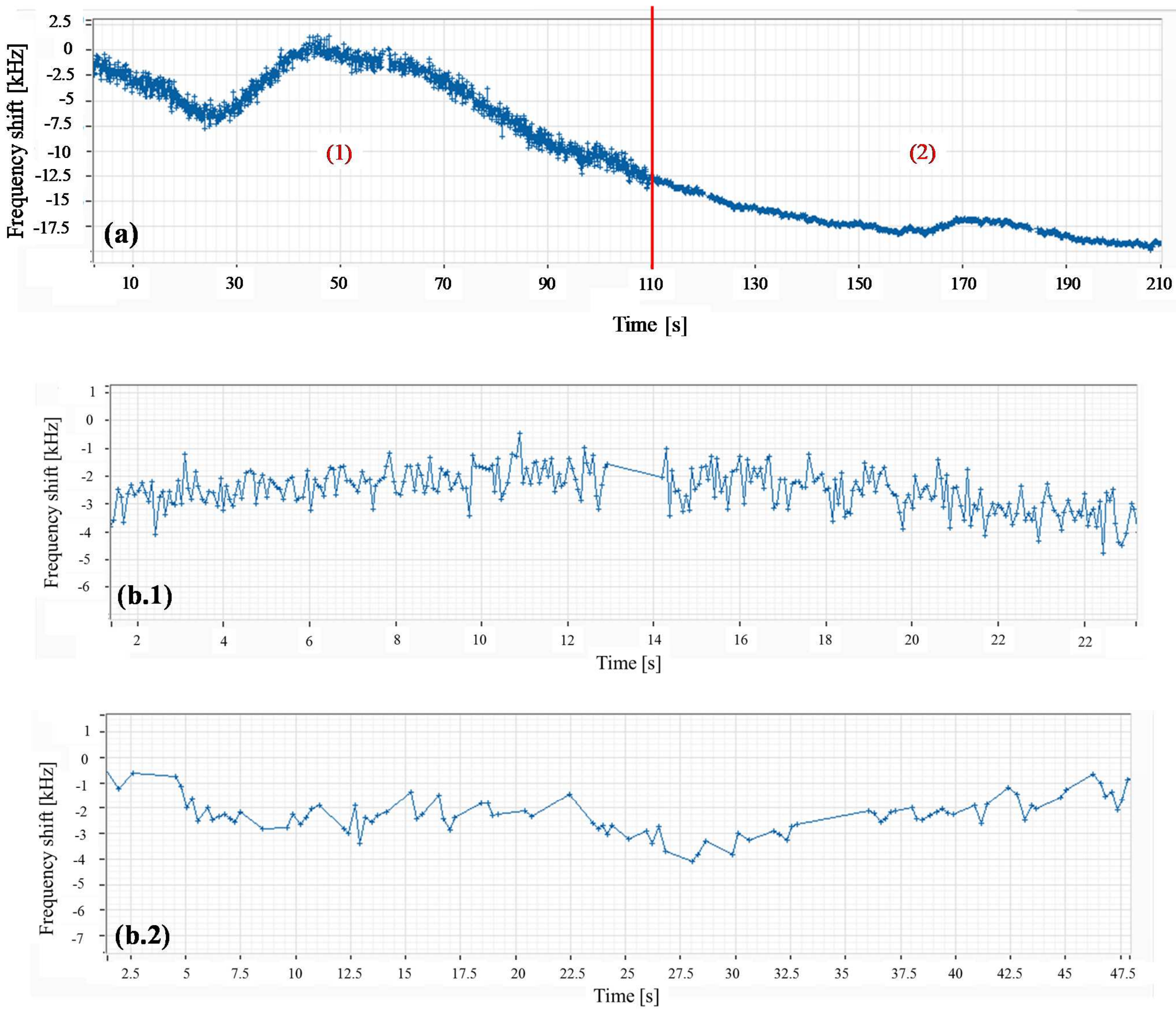

Fig. 4. Frequency shift readout vs. time for varying IF bandwidth and number of points. (a) 500 points with IF = 30 kHz for zone 1 and IF = 1 kHz for zone 2. (b) IF = 30 kHz for both b.1 and b.2, but 500 points for b.1 and 2000 points for b.2.

IV. CONCLUSIONS

We have studied how the readout parameters of a portable NA influence the final performance of an electroacoustic sensor, particularly our AlN-based SMR. Our acquisition system is based on the peak fitting using a specific algorithm for precise extraction of the peak frequency. Hence, not only the configuration of the NA, but also the quality of the peak directly affects the data extraction performance. We compared peaks with spurious mode presence and without. We have observed LoDs below 0.5 kHz for high quality peaks, while in contrast, the presence of spurious modes increases the LoD up to 10 kHz or even higher. Regarding the acquisition time, if we use a high-quality peak, the acquisition time can go below 100 ms considering less than 1000 points over a span of 10 MHz. It increases up to 20 s with 10000 points. As for the IF bandwidth of the NA, a variation from 1 kHz to 30 kHz can lead to a sevenfold increase of the sensors LoD for the same amount of points. The final performance of an FBAR sensor will be directly influenced by the NA readout parameters and tradeoff between LoD and acquisition times need to be considered.

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