MEASUREMENT OF NONLINEAR EFFECTS IN FILTERS 
BASED ON BAW RESONATORS WITH AlN

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Abstract. Bulk acoustic wave BAW technologies offer notable advantages for filters in RF applications. This paper reports the measurement results for the intermodulation effect and the amplitude-frequency effect of a filter at high power levels. The filter incorporates three power BAW resonators. The possible origin of this behavior is discussed.

Keywords: communications circuits, power BAW resonators and filters.

1. INTRODUCTION

The thin film technology reached in the last years higher operation frequencies than that obtainable with the classical quartz piezoelectric resonators. A strong candidate in this area is the AlN bulk acoustic wave (BAW) technology, which emerged in the last several years as an efficient solution for communication filters, due to its low price and compatibility with CMOS technology.

In order to maintain a high quality factor The BAW resonators it is mandatory to prevent the mechanical wave energy to be lost in heating the substrate. To this end two manufacturing solutions are known: the film bulk acoustic resonator (FBAR - Fig. 1 a) using an air gap and the solidly mounted acoustic resonator (SMR - Fig. 1 b) employing a Bragg mirror containing reflector layers.

These resonators operate in the thickness mode, so the 1D model of the electromechanical field on this direction can reproduce quite well the device behavior.
The influence of these nonlinear effects has to be taken into account in circuit design, if these devices are used for building a duplexer filter for mobile communications. To achieve this goal, some behavioral models which can reproduce the effects mentioned above have been developed [3]. One of these models uses elements that have polynomial nonlinearities for all the elements in the BVD circuit, except $C_0$ which remains linear.

2. MEASUREMENT OF THE INTERMODULATION EFFECT

Figure 4 presents the schematics and the measurement bench using the following notations: VNA – Vector Network Analyzer, SA - signal analyzer, PA - power amplifier, C1 to C6 - circulators, LPF - low pass filter, ATT - attenuator, DUT - device under test. A similar test bench has been presented in [4]. The only notable difference is that because the measurements were made in the transmission mode, i.e. incident power only are measured, the coupler was replaced by the DUT.

The DUT is a filter (Fig. 5) built using three BAW resonators. The $X_1$ and $X_2$ resonators are identical and have the series resonance frequency at approximately 2.18 GHz and the parallel resonance frequency at around 2.19 GHz. The $X_3$ resonator has the parallel resonance equal to the series resonance of the $X_1$ and $X_2$ resonators, namely 2.18 GHz, and the series resonance frequency fixed at approximately 2.06 GHz.

As it is shown in Fig. 4, the DUT is a two-port device that has the input port 1-1’ and the output port 2-2’.

The measurements were made in transmission mode, i.e. the input signal has been applied to the port 1-1’ and the output signal has been acquired at the port 2-2’ and fed directly into the VNA input port.

The DUT, Fig. 5, is connected to the measurement bench through the wire bonding method. This type of connection introduces some parasitic elements in the measurement chain and its parameters can be identified by solving some electromagnetic field problems [5]. $X_1$ and $X_2$ are apodized resonators with an area of 32000 µm$^2$ each, while $X_3$ is apodized also having an area of 44000 µm$^2$. The filter cross-section form is given in Fig. 6.

![Figure 4. Measurement bench](image)

![Figure 5. Filter design](image)

![Figure 6. The cross-section of the filter](image)

![Figure 7. The 2f output power vs. frequency](image)
The DUT was driven by a sinusoidal signal in the frequency range 2 GHz - 2.2 GHz. The measured results for the 2f output power are given in Fig. 7 while those corresponding to the 3f output power are presented in Fig. 8. Three input power levels have been used for these measurements: 30 dBm, 31 dBm and 33 dBm.

The frequency characteristics in Fig. 7 and Fig. 8 have been built using the results obtained for 801 frequencies at each input power level. In order to avoid device overheating, that can lead to some measurement errors and even can destroy the DUT, a pause of 100ms (for incident power levels under 30 dBm) or one of 10s (for incident power levels greater than this value) is programmed after each measurement.

3. MEASUREMENT OF THE AMPLITUDE - FREQUENCY EFFECT

The amplitude-frequency effect for the filter in Fig. 5 is presented in Fig. 9.

For a better visualization of this effect, some details of the frequency characteristics are given as follows:
- the pass-band (Fig. 10),
- between the lower stop-band and the pass-band (Fig. 11),
- between the pass-band and the higher stop-band (Fig. 12)

The measurement between 2.06 GHz and 2.12 GHz respectively the left side of the measurement between 2.17 GHz and 2.2 GHz are shown.

From Fig. 9 can be observed the displacement of the characteristic to the left while the power increases and from Fig. 10 the displacement of the characteristic to the right as the power increase.

4. CONCLUSIONS

Both the second harmonic distortion and the amplitude-frequency effect can influence the correct operation of a RF filter. This is because a behavioral model reproducing both effects is very useful in RF circuit design. The model described in [6] is able to reproduce the intermodulation effect, but doesn’t exhibit the amplitude-frequency effect. The model proposed in [7] uses a mechanical nonlinearity so it may be able to
reproduce both the amplitude-frequency effect and the intermodulation effect; but no comparison between measured and simulated amplitude-frequency effect is provided by the authors.
Our future work will be devoted to build a behavioral model for this filter, using the behavioral resonator models described in [3] and [5].

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5. REFERENCES