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Measures and Influence of a Baw Filter on Digital Radio-Communications Signals

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***Abstract*—**This work concerns the measurements of a Bulk Acoustic Waves (BAW) emission filter S parameters and compare with prototypes simulated types. Thanks to HP-ADS, a co-simulation of filters' characteristics in a digital radio-communication chain is performed. Four cases of modulation schemes are studied in order to illustrate the impact of the spectral occupation of the modulated signal. Results of simulations and co-simulation are given in terms of Error Vector Measurements to be useful for a general sensibility analysis of 4th/3rd Generation (G.) emitters (wideband QAM and OFDM signals)

***Keywords*—** RF architectures, BAW filters.

I. FILTER MEASUREMENTS AND COMPARISON

CURRENTLY, BAW filters are supposed to be used for 4th/3rd G. standards and beyond as emission filters. They can offer a good selectivity and reduce the total size of the transmitter [1][2][3][4][5]. The effect of electrical parameters of such filters in a radio-communication chain is not accurately quantified yet. Amplitude, phase and group delay variations are a key point to study in order to evaluate the influence on the signal quality. Quality decrease that will occur is to be compared with sensibility analysis of emitter architectures for these types of signals [6]. Specifications for these applications are given here by the impact of the filter on the EVM (Error Vector Magnitude). This paper is to characterize the influence of a given BAW filter [1] response when it is used in a radio-communication link for wideband complex modulation.First, the comparison with prototype filters is presented and second is simulations of four modulations cases, representing some of 4th/3rd G. signals. The emitted power dependency on the filter response is considered here and approximated by preliminary measurements. Principle of the high signals analysis is exposed at the end of simulations results. In order to compare with prototype filters, the BAW filter, an Agilent ACPF 7001 represented in figure 1, is measured thanks to a VNA (Vector Network Analyzer).S parameters of the filter are measured from 1.7 to 2.1 GHz (UMTS/LTE bands) as it can be seen on figure 2. The pass-band of the ACPF is 1.84 to 1.91 GHz. Return loss measurement corresponds well to datasheet specifications. Also the attenuation in the stop-band is in the range of 30 dB. The phase response of figure 1 is not very linear and figure 4 shows a maximum delay variation of 30 nano-secondes (nsec) on the whole bandwidth (worse case). Three filter types are considered here to make a comparison in terms of amplitude and/or group delay response: Butterworth (N=12, 70 MHz passband), Chebychev (N=7, 80 MHz passband) and Cauer (N=3, 62 MHZ passband). Common parameters used in ADS simulator are an Insertion Loss (IL) of 2.2 dB and a center frequency of 1.88 GHz to fit the filter measurements. First is the comparison in terms of amplitude variation, as shown on figures 2 and 3. As we can see on a wide frequency range, the Cauer type filter seems to be the best approximation of the measured BAW filter response, considering only the $|S_{21}|$ parameter.

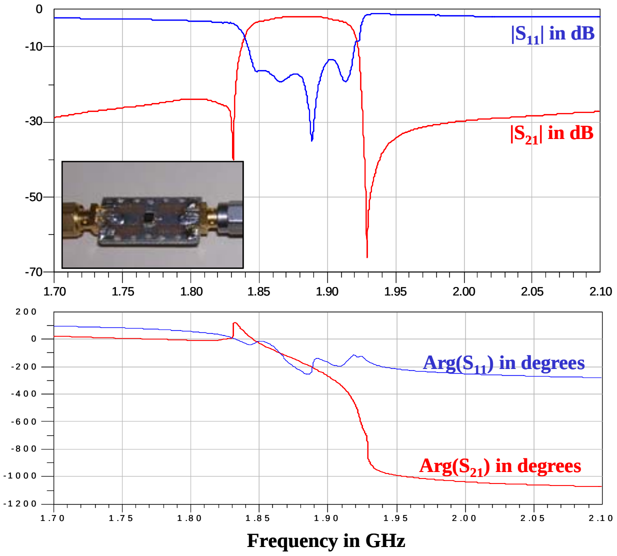

Fig. 1 Measurements of a BAW ACPF7001 filter

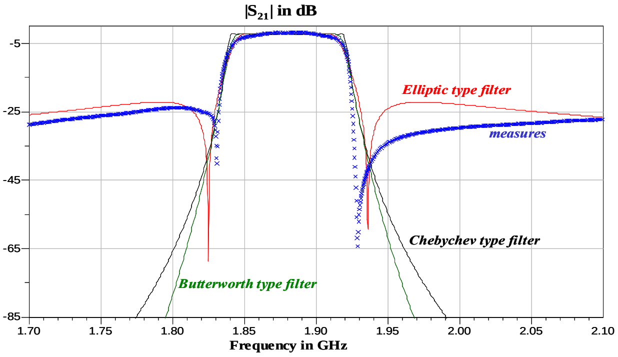

Fig. 2 $20.\log_{10}(|S_{21}|)$ of the different filter types

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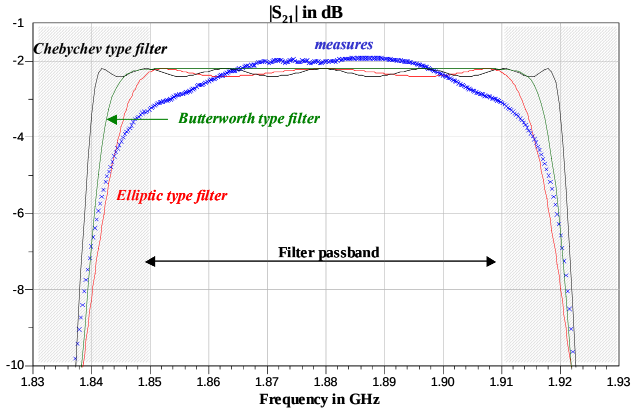

Fig. 3 $20*\log_{10}|S_{21}|$ of the different filter types

Although the behaviour matches well in the stop band, the pass-band ripples of prototypes filters are to be minimized because it is an approximation error between amplitude response of the measured (BAW filter) and simulated filters, as shown on figure 3. The problem here is that the BAW filter transfer response is not constant but with no ripple in the pass-band and has a high selectivity.

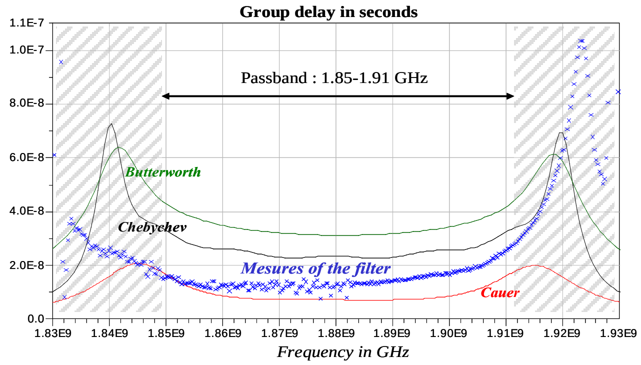

Fig. 4 Group delay of the different filter types

Filter group delay characteristics are compared on figure 4 and show the non symmetry mismatches. Again, the Cauer filter type seems to be in the range of the measured filter response but the slope of the variation is not in the same level. In the following part we do the co-simulation, which is the introduction of emission filter S-parameters in the digital simulation, with the Cauer and the Butterworth type filter to compare with the S-parameters measures. The Butterworth type has no ripple and no amplitude variation in the pass-band on the contrary to its phase response. This is a good indicator of group delay influence only.

II. INFLUENCE ON $4^{TH}/3^{RD}$ G. SIGNALS

A radio communication link is simulated under HP-ADS where S parameters measurements of the BAW filter at the emission are introduced. Two others simulations are made at the same time, corresponding to the use of a Butterworth and a Cauer type filter. Results are quantified in terms of Error Vector Measurement (EVM) rms. Four cases of modulation types are simulated over the total pass-band of the filter.

Case A: 3π/8-8PSK, 500kHz. This modulation case is considered as a narrowband one at such a center frequency of 1.88 GHz, representing a typical EDGE modulation case. We use a raised cosine shape filter type instead of the gaussian one to clearly see the trajectory of the signal in figure 5. Results are presented in function of the carrier frequency over the pass-band of the filter. EVM is not growing much from 0.1% for the best case at 1.88 GHz to 0.6% for the worse one at 1.905 GHz. The emitted constellation in the worst case is represented on figure 5 (left). This case remains very insensitive to the filter characteristics because of the narrow 500 kHz bandwidth that represents less than 0.1% of the carrier frequency.

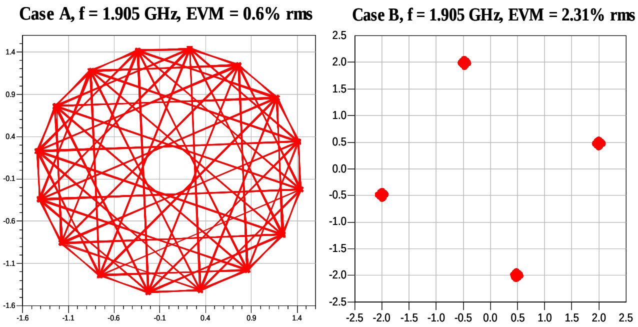

Fig. 5 Constellations at 1.905 GHz, case A and B

Case B: QPSK, 2MHz. In 3rd generation standards, modulations have a higher bandwidth than case A, due to the increase of the data transfer rate (spectrum efficiency needed). Results, in case B, are that EVM is much more dependant of the filter characteristics than in the previous case. In fact, the worst result is for 1.905 GHz carrier frequency as reported on figure 9. EVM in this case is 2.31 %, that is an important value considering potential others imperfections in the transmitter.

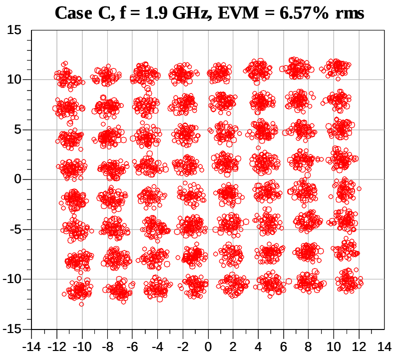

Fig. 6 Constellation at 1.9 GHz, case C

Case C: 64QAM, 10 MHz. The case C is not directly dependant of a given standard but uses a wide 10 MHz 64QAM modulation to demonstrate the high influence of the modulation bandwidth on the emitted signal quality. Figure 6 shows the 6.57 % EVM case. This important value is by far too high to enable a correct transmission of the information. 10 MHz represents a spectral occupation of only 0.5% of the carrier frequency. This is a high disadvantage for the use of BAW filter with wide bandwidth modulated signals.***Case D: 16QAM-OFDM64, 20 MHz.*** Another case is introduced in the simulation and corresponds to OFDM (64 sub-carriers) standards such as IEEE802.11, WIMAX… Results are EVM values inferior to that of the case C. This is accomplished because the algorithm used an equalizer **on each sub-carriers** for the EVM evaluation. If the correction is applied like that, EVM decreases from higher values than in case C to the range of 2 to 3 % *rms*, see figure 7.

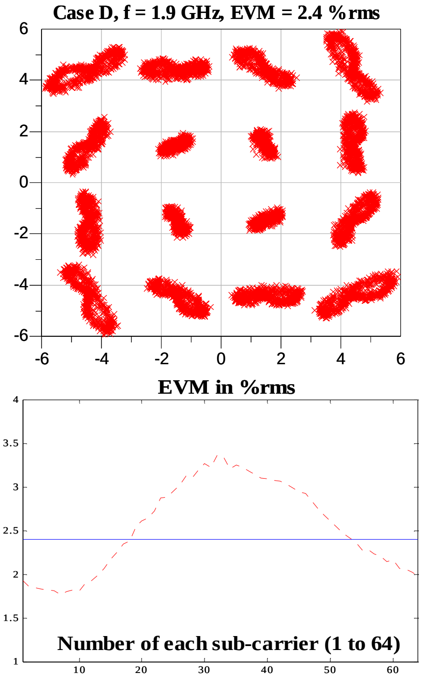

Fig. 7 Constellation and EVM (all sub-carriers)

The constellation shown is surprising considering the 2.4% rms EVM value. This is because figure 11 is the plot of all sub-carriers constellations superposed. In fact, different amplitude and group delay variations are applied on each sub-carriers that uses each (20/64) MHz = 312.5 kHz bandwidth 16QAM modulation scheme. Consequences are a different EVM value on each sub-carriers, as shown in the figure 7. For this wideband OFDM signal, the average 2.4% EVM value is due to the correction algorithm applied, specified by the standard. For the different filter types used in the ADS co-simulation (emission filter in the radio communication link) and for the measured BAW filter, the EVM is plotted at the different carrier frequencies of the emitted signal. We can see in figure 8 the frequency dependence for the four modulation schemes. Global results demonstrate the non symmetry of the filter characteristics. Due to EVM algorithm calculation, case D results are better than case C. The use of wideband OFDM signals with this filter characteristics are then conditioned by this signal processing equalization. Results of Butterworth type filter influence points the fact that the group delay is the major source of degradation because the Cauer type simulation causes EVM in lower range. Also, the growing of EVM in the three plots of figure 8 corresponds for a great part to group delay variation. For modulation such as cases A, B and D, the EVM value is smaller than 2% for most part of the frequency band considered. These results are encouraging for the potential use of BAW filters in 4th/3rd G. systems but they are to be confirmed by the study of their electrical characteristics power dependency.

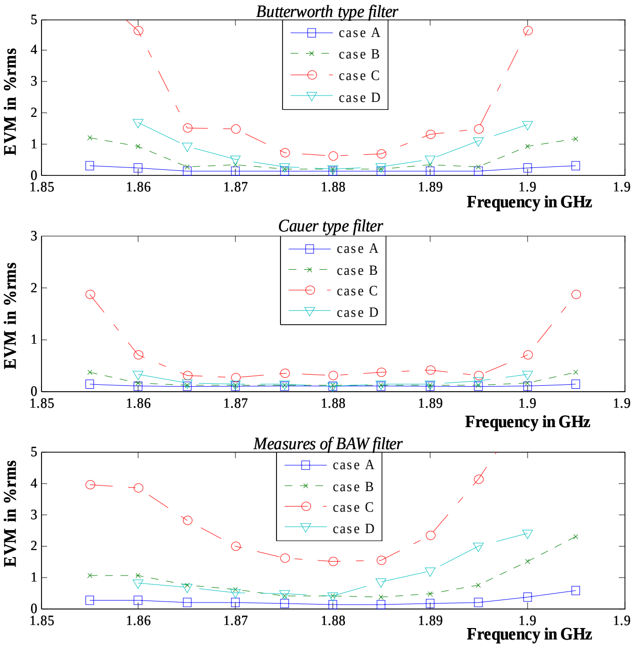

Fig. 8 EVM in function of the (co-)simulated filter

III. SIGNAL POWER VARIATION SIMULATION

The emission filter is to be used for any type of modulated signals. Modulation used herein often implies an instantaneous power variation, usually identified as the envelope variation. The important characteristic of the BAW filter, its frequency response, varies with the power of the signal. This is observed by measuring S parameters with a VNA at different input power levels. The resulting information is indexed inside a data base. If we made the hypothesis that at a given instantaneous power level P, parameters of the filter are updated to the corresponding behavior in frequency indexed by P, it is possible to build an adaptative algorithm to filter power varying signal. As modulated signal are in fact power varying signal, it is implies to estimate P in function of the time. In order to adapt in time the response of the filter it is necessary to work with the impulse time response data base corresponding to the measured frequency response. Principle of the algorithm is reported in figure 9 and equation (1).

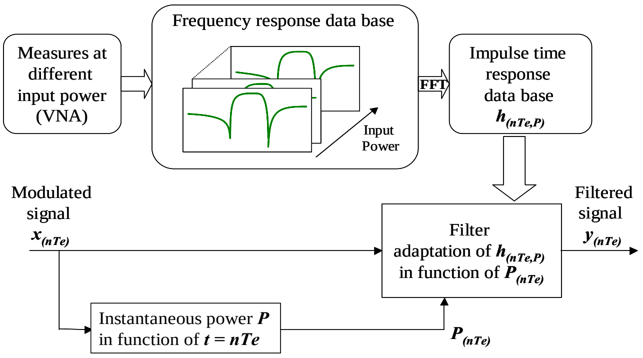

Fig. 9 Principle of the algorithm

$$y_{(nT_e)} = h * x_{(nT_e)} = \sum_{i=0}^{i=L-1} h_{(i,P_{(nT_e)})} \cdot x_{(nT_e - iT_e)} \qquad (1)$$

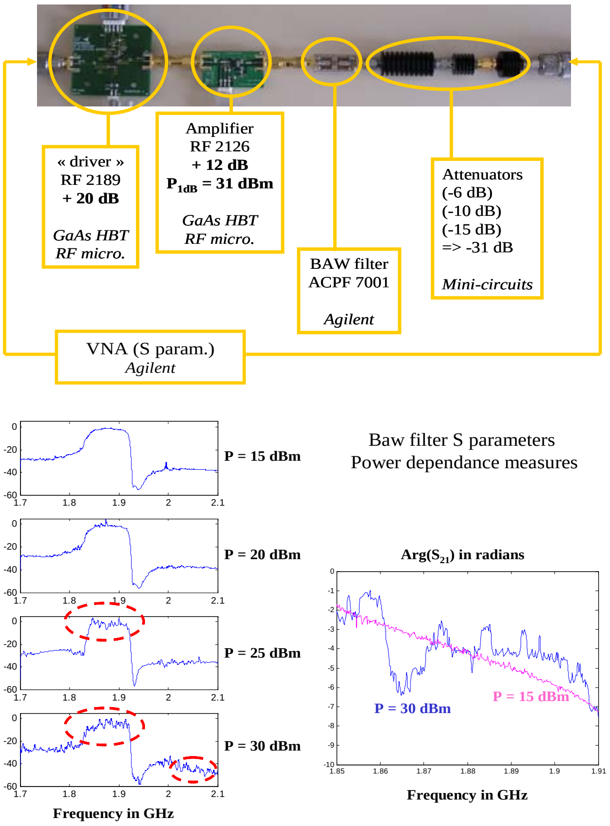

Fig. 10 Measures (top) and extraction of S21

The simulation is done thanks to MATLAB, with sampled signal (Fe = 40 GHz) and adapted to the power level at which measures were done, with a step of 0.5 dBm. Results are an increase in EVM from 1.9 to 2.1 %rms, for a 16 QAM (case C) 10 MHz modulation at a carrier frequency of 1.88 GHz and a mean power level of 10 dBm. This algorithm is an advantage in the characterization of BAW filter's parameters impact on modulated signals. It enables to reintroduce measurements in the simulation of a modulated signal at different symbol rate and power level. S parameters measurements for high power levels imply an extra step of drivers and PA de-embedding see figure 10. We can point also that this simulation is based on the fact that the filter reacts instantaneously to the power level. Memory effects and dynamic behavior of the filter are not yet introduced in the algorithm. We also study the impact of group delay at high power level and large band-width (high data rate) signals. High power measurements, up to 30 dBm, are done in the configuration exposed in figure 10. These measurements demonstrate the mandatory limitation due to power influence on filter response. Also the influence on modulated signals (several MHz) will be worst than the results obtained for single carrier measurements. Further measures are needed for building a non-linear model, based on the simulation exposed.

IV. CONCLUSION

In this paper, measured characteristics of a BAW emission filter were compared to prototype filters. A co-simulation quantifies the influence on the EVM, in a communication chain. High power measurements are reported and the principle of reintroducing this influence in a simulation is exposed. It is not easy to compare filter such as BAW to classical Cauer, Butterworth and Chebychev. The comparison must be done at least with a Butterworth filter to show the impact of phase filter response only on the emitted signal. Results are that group delay characteristic has the strongest impact on the EVM. The decrease is directly linked to the frequency bandwidth of the modulation. This is all the more important for 4th/3rd G. standards than the need of high data rate transfer implies the use of a spectrum efficient and wideband modulation schemes. EVM are in an important range of 2 to 3% rms but this could be taken into account in the overall architecture imperfections analysis. The problem now is to focus on power dependency of the BAW filter's parameters because this will worsen performances. Thanks to high power variation measurements, we can expose that this type of filter behaves like a non-linear components with AM/AM and AM/PM characteristics. Its behaviour can be modelled and should be taken into account for the architecture linearization method (correction or linear architecture).

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