Practical High Power Characterization of Resonant Piezoelectric Vibrators

Introduction

The admittance of piezoelectric resonators and ultrasonic motors strongly depends on the applied field. As a consequence the constitutive equations (1) and (2) cannot adequately describe the piezoelectric effect for large swings of the applied field and are best used for the effect´s linear region that develops at small electric fields.

$$S = s_E \cdot T + d^t \cdot E \qquad (1)$$

$$D = d \cdot T + \varepsilon_T \cdot E \qquad (2)$$

In this area the admittance of a piezoelectric resonator matches the admittance of the equivalent circuit shown in Fig. 1.

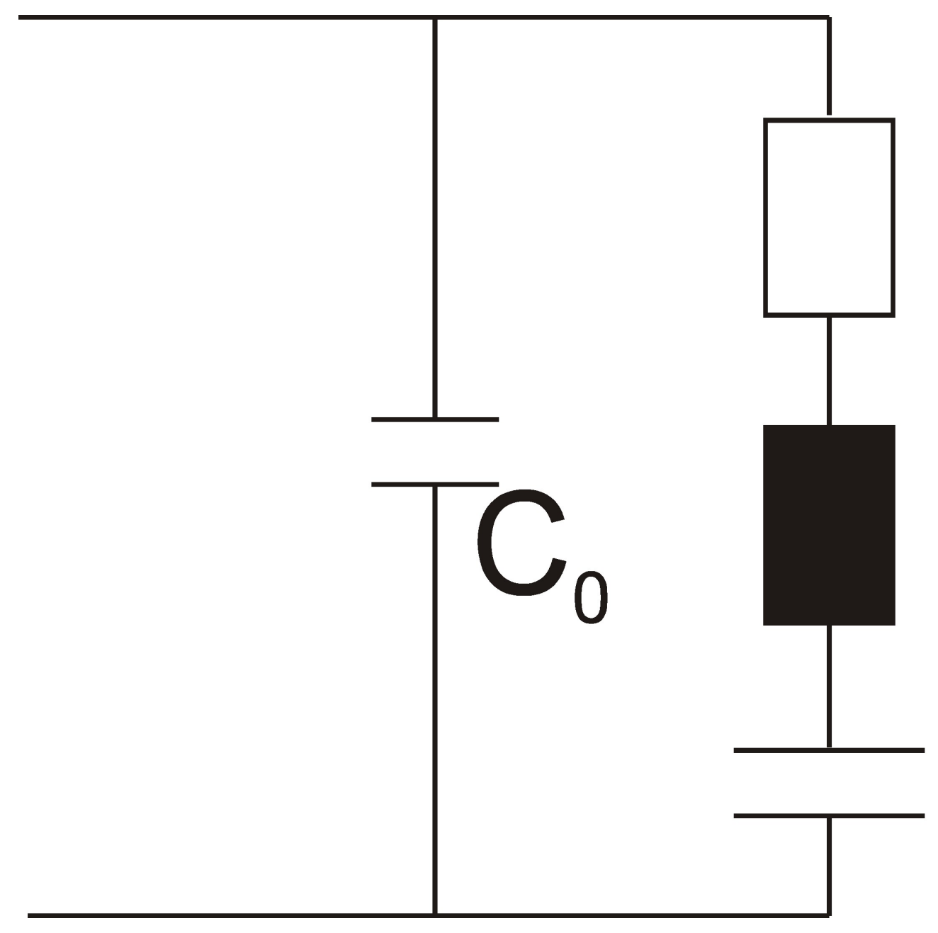


Fig. 1: Small signal equivalent circuit

Technical vibrators, however, are excited at high voltage levels with switched inverters, operate under heavy mechanical loading or drive a frictional contact as in the case of ultrasonic motors. Optimum operating conditions can be satisfied only by using electrical filter circuits and matching the resonator to the power supply to obtain a high electrical efficiency.

Test Bench for Large Signal Admittance

Fig 2 shows the schematic of a test bench to measure the admittance of resonators at higher electric fields. The measurement signal is generated with four quadrant amplifiers that generate a maximum output current of 3 A at 160 V amplitude. The controlling signal comes from a two-phase frequency generator. Voltage and current are measured using a scope and a shunt resistor. A LABVIEW program controls the setup using GPIB to supply the frequency generator with amplitude and frequency values and receive data from the scope.

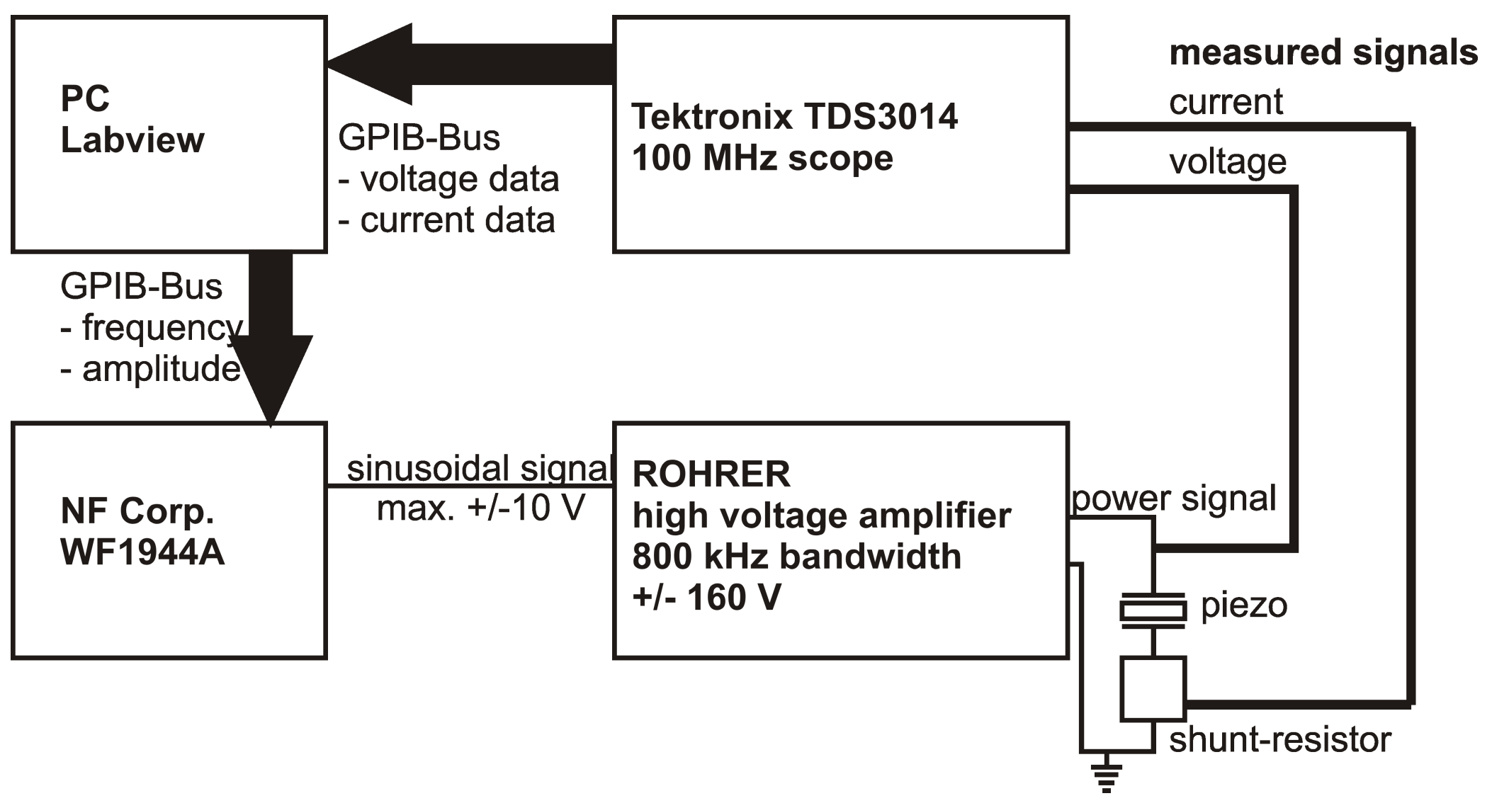


Fig. 2: Communication strategy

The LABVIEW program performs frequency sweeps and displays the resonator admittance in a bode plot and in the complex plane. The setup allows single phase and multiple phase ultrasonic motors to be analyzed in operation using a second amplifier. Fig. 3 shows the workstation. An impedance analyzer from Solartron Analytical is available for reference measurements.

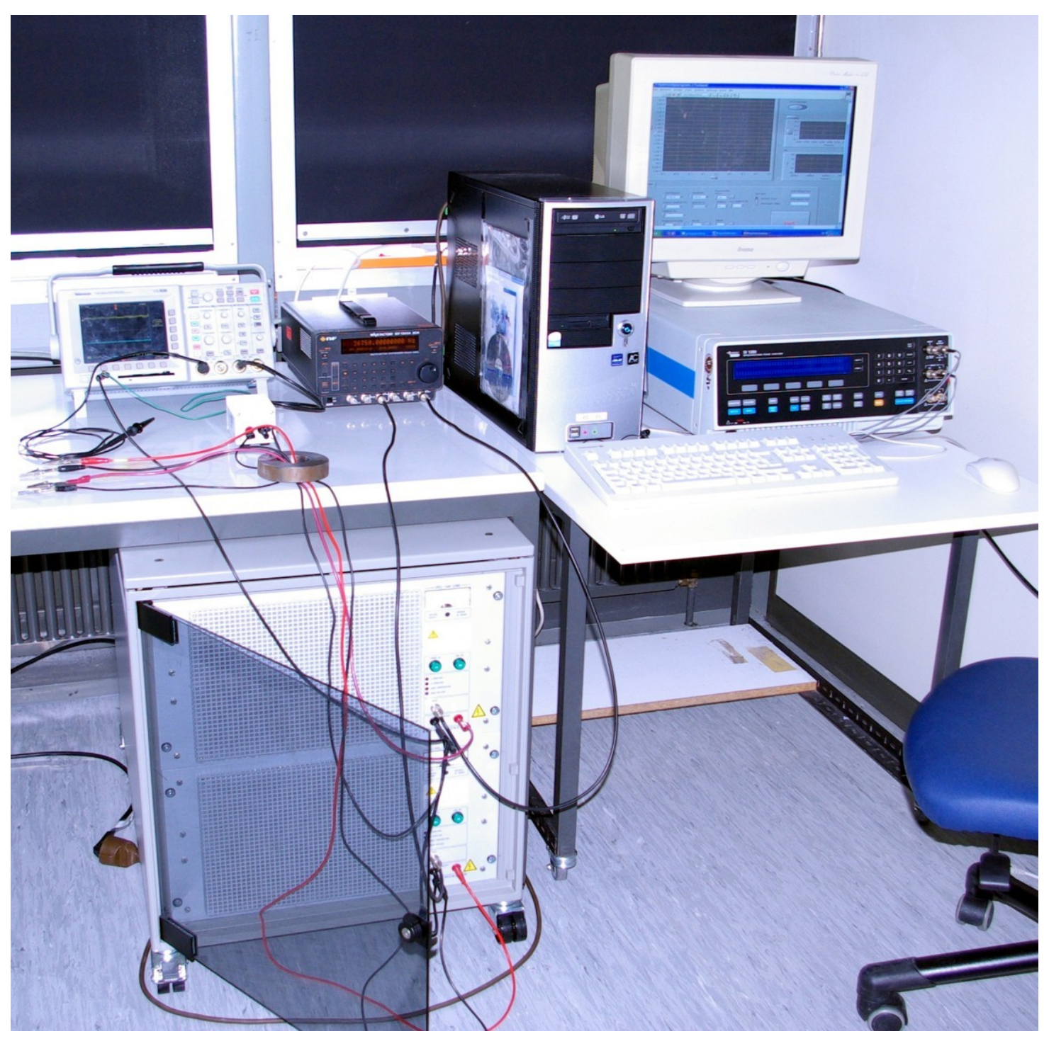


Fig. 3: Large signal test bench

Free Vibration at Strong Electric Fields

Strong electric fields produce changes in the admittance of piezoelectric resonators. The resonance frequency lowers partly due to heat generation and a decreasing stiffness of the material in resonance. Fig. 4 shows the admittance of a freely vibrating piezoelectric block resonator made of PZ26 from Ferroperm vibrating in the first longitudinal mode.

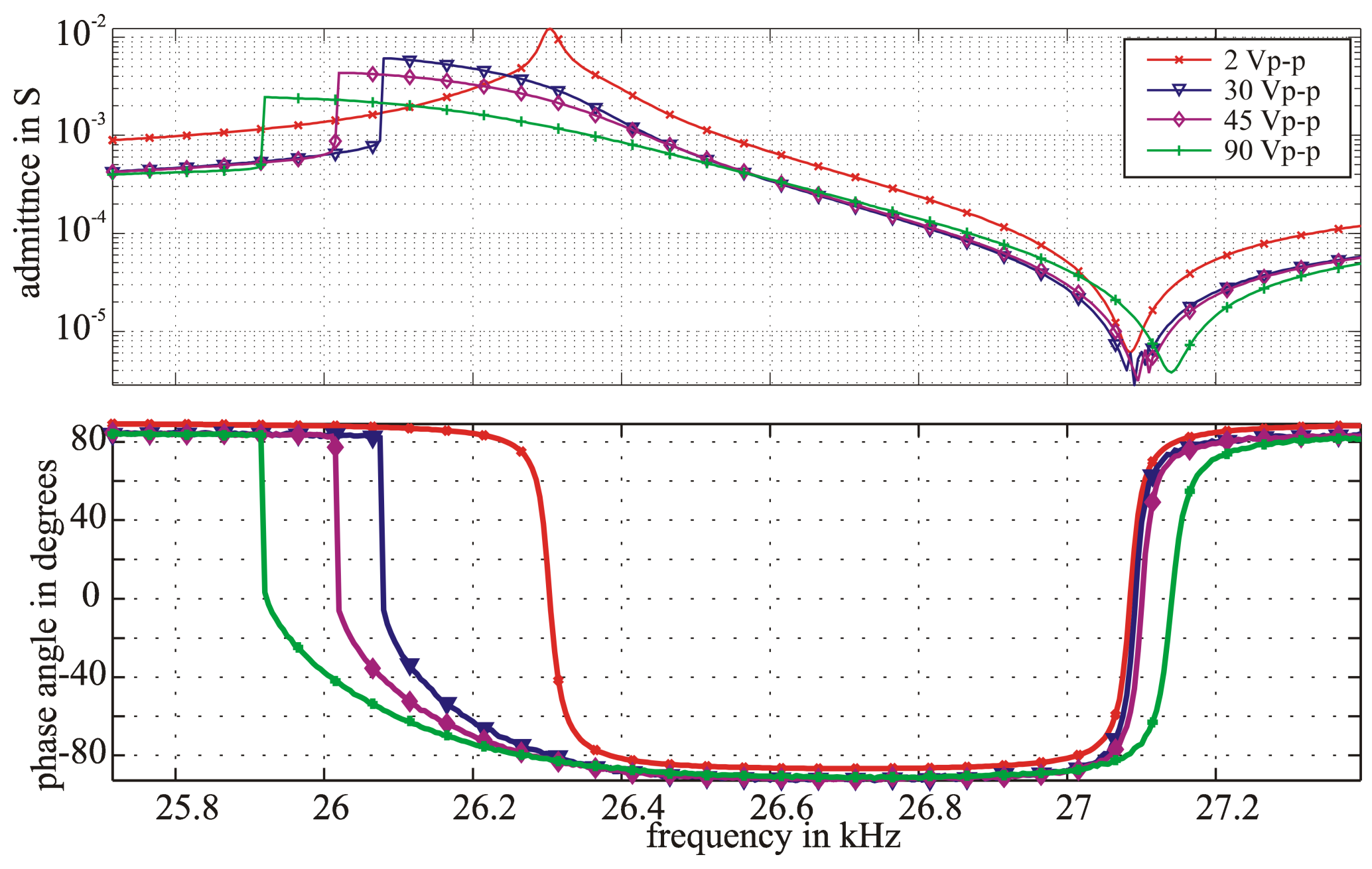


Fig. 4: Admittance shifting by field strength

The dimensions are 60x20x5 mm . At 2 V the admittance is measured using the impedance analyzer. There the resonator has a high mechanical Q and a resonance frequency of 26305 Hz. However at higher voltages the resonance frequency shifts and a magnitude jump of the admittance occurs. At 90 V the resonance frequency is 380 Hz lower than at 2 V and the admittance is reduced by a factor three. The measurements show results from a down-sweep. Different values of the jump frequency will be measured depending on the sweep direction. Fig. 5 depicts this characteristic behavior. Resonators need to be driven above this threshold frequency range in order to produce stable high amplitude vibrations.

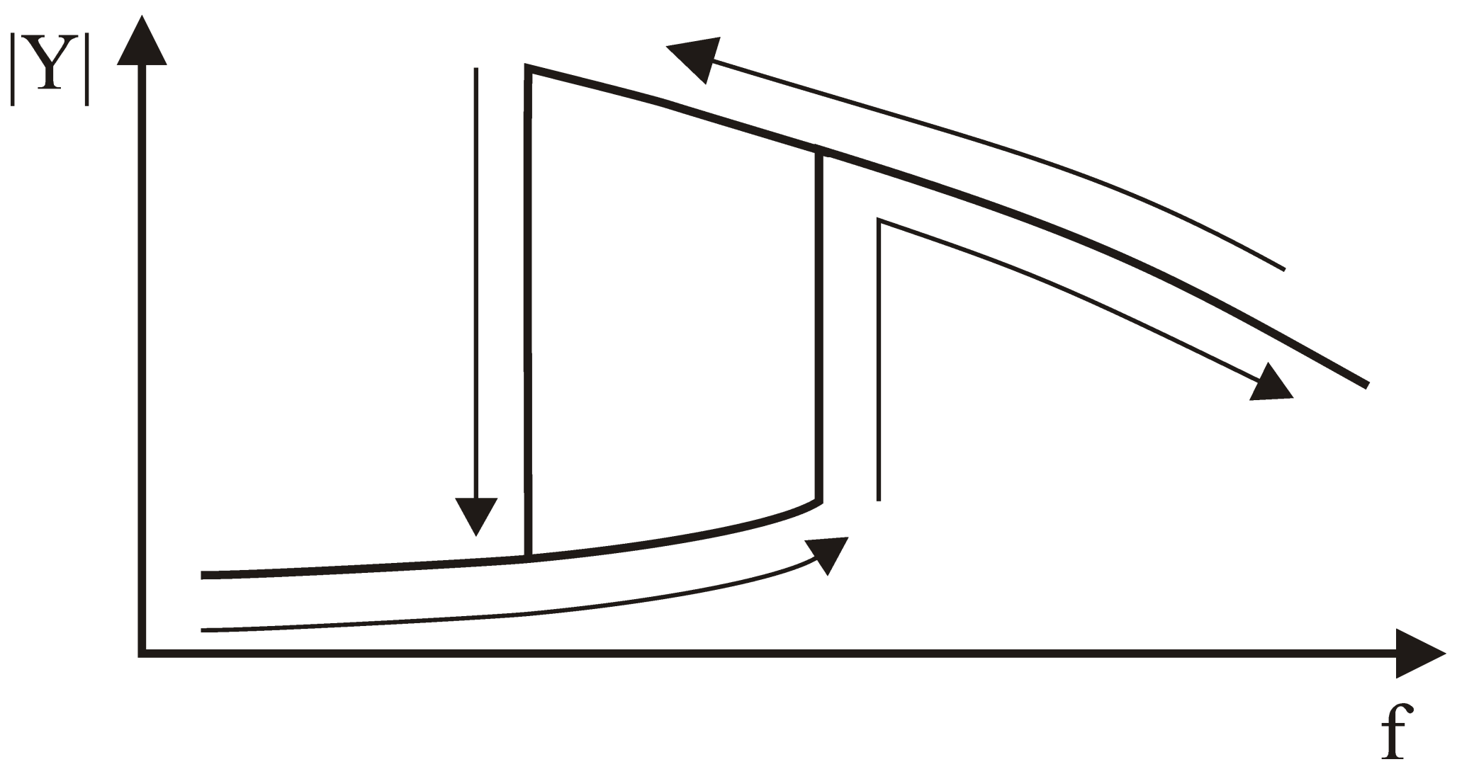
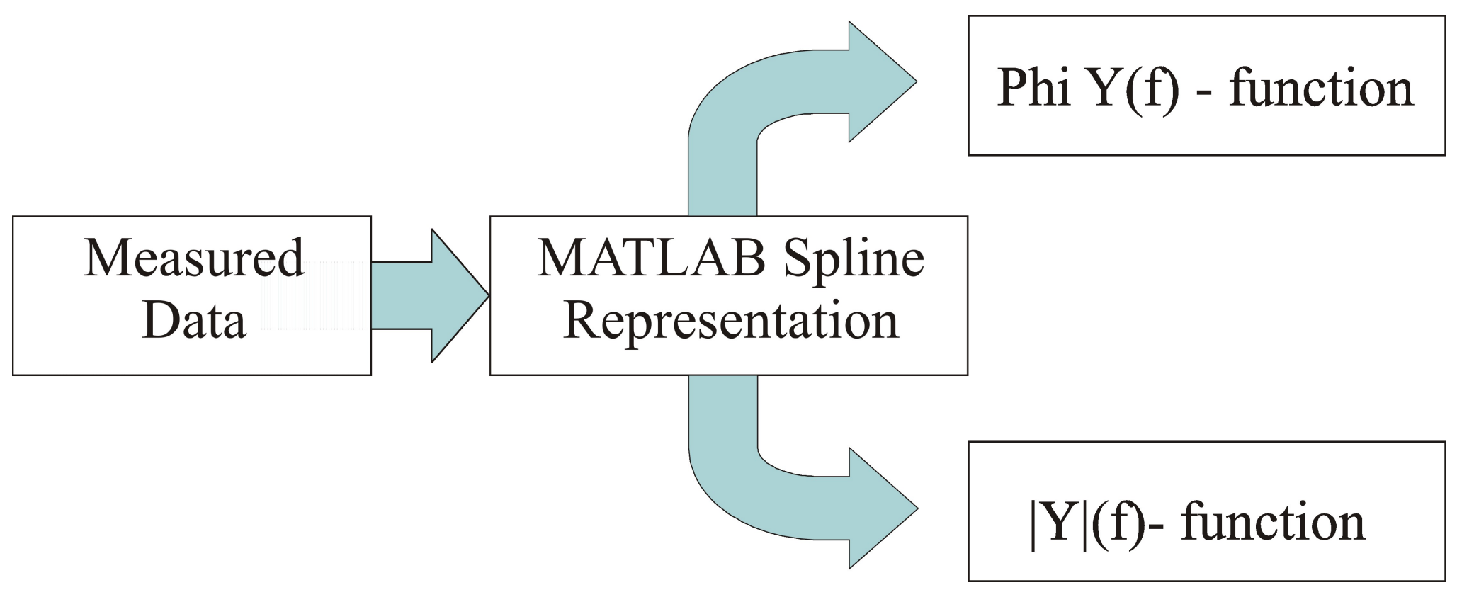


Fig. 5: Frequency hysteresis

Modeling

Filter circuits are needed to shape the inverter output and the admittance of the load determines the size of necessary ferrite cores for transformers and inductors. As the resonator shows a lowered admittance at stronger fields this must be considered. The small signal equivalent circuit cannot describe the effect. Therefore a design based on the admittance at the operating voltage is favored over free vibration measurement results and will produce smaller ferrite cores. For the analysis the admittance data is represented with a Matlab spline function, Fig. 6, and the transfer function is used to compute currents and voltages in the inductive components.



Measured Data

MATLAB Spline Representation

Phi Y(f) - function

|Y|(f)- function

Fig. 6: Large signal admittance modeling

Ultrasonic Motor Admittance

For motors in operation the influence of the mechanical contact needs to be analyzed. A dual mode ultrasonic motor based on the the first longitudinal (L1) and the second bending mode(B2) is examined, Fig. 7.

Fig. 7: Dual mode resonator

A fixture with wheels generates a continuous state of operation for the resonator. Fig. 8. shows the admittance of the bending mode. The B2 admittance during motor operation shows the influence of both modes. Compared to free vibration the admittance is significantly lowered due to the work performed on the frictional contact. It is clear that both modes have been separated due to the preload and so the resonator can be further optimized using these measurements.

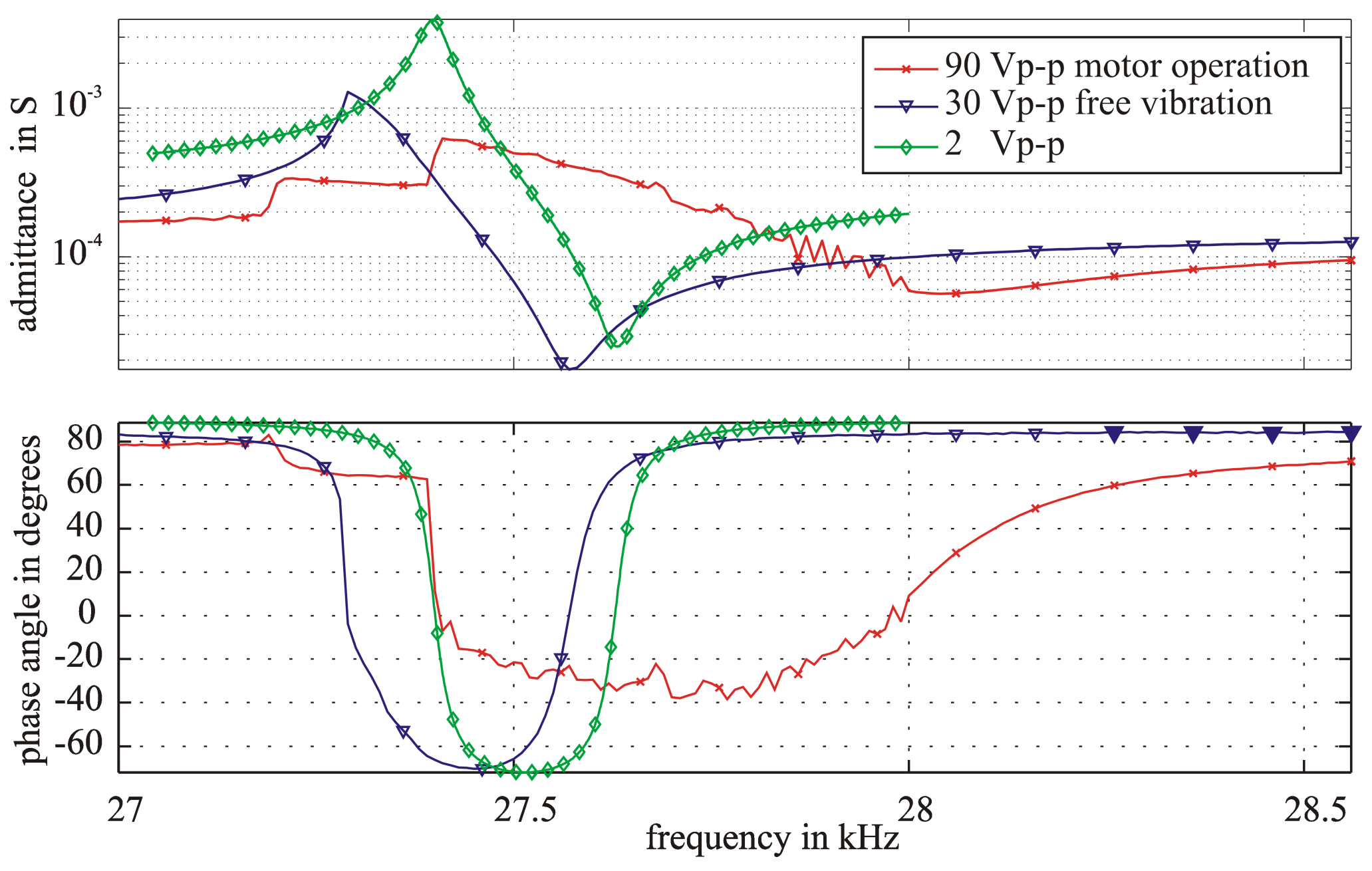


Fig. 8: Free vs. operating admittance

Conclusion

High field strength based filter analysis of ultrasonic resonators reduces the size of inductive components as it includes operating point data into the analysis of filter circuits. The presented method is thus a valuable addition to small signal analysis and allows further geometric optimization.

Kontakt:
IKFF Universität Stuttgart
Tel.: 0711 / 685 66402
Fax: 0711 / 685 56402
E-Mail: piezoantriebe@ikff.uni-stuttgart.de

Universität Stuttgart
Institut für Konstruktion und Fertigung in der Feinwerktechnik

Pfaffenwaldring 9
70550 Stuttgart