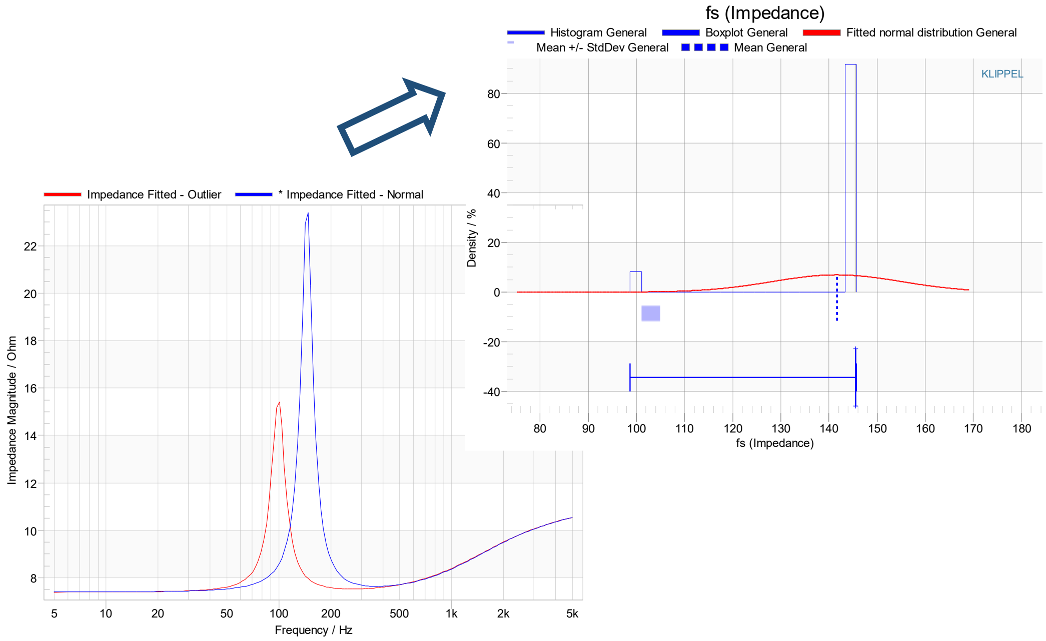
Tolerances of resonance frequency f_s

AN42

Application Note to the KLIPPEL R&D (Document Revision 1.2)

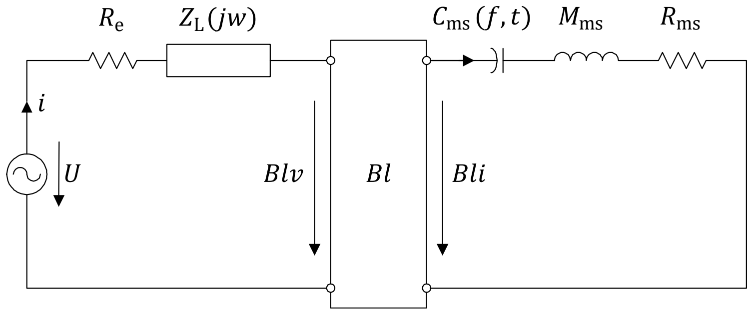
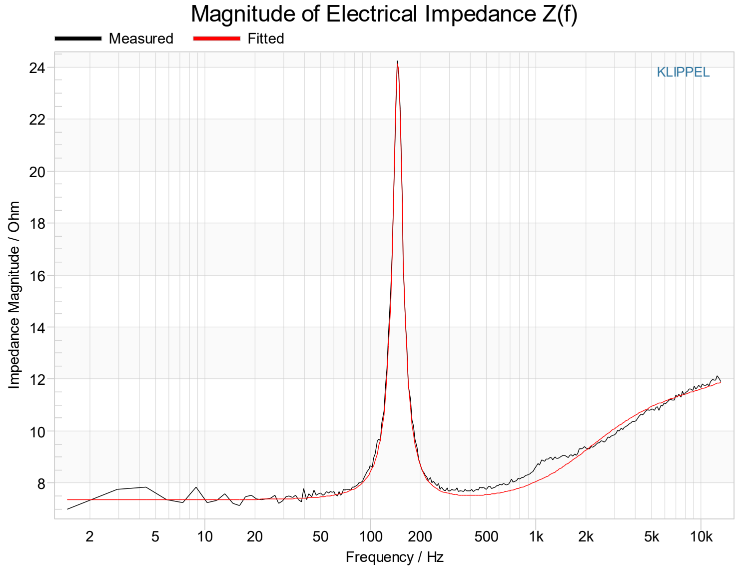
DESCRIPTION

The fundamental resonance frequency f_s is one of the most important lumped parameters of a drive unit. However, the measured value of f_s may vary from unit to unit and may also depend on the measurement conditions. This paper reports from a systematic investigation and a statistical investigation of multiple units of 4 loudspeaker types. The results from an analysis of variances shows that the dominant factors of influence are peak to peak displacement, climate and history of the measurement. The application note gives practical tips how to perform reliable measurements and define meaningful tolerances.



CONTENT

1 Introduction

Physical causes	 The moving mass M_{ms} and the compliance C_{ms} generate a vibrating system with a resonance frequency: $$f_s = \frac{1}{2\pi}\sqrt{\frac{1}{M_{ms}C_{ms}}}$$ The suspension parts (spider and surround) and the enclosed air (e.g. below the dust cap) determines the mechanical compliance $C_{ms}(f,t)$. This parameter varies significantly with displacement, time and depends on the ambient conditions (temperature and humidity). The moving mass M_{ms} considers the mass of the moving loudspeaker parts and the air load.
Measurement of resonance frequency	The maximum in the electrical input impedance $Z(f)$ reveals the fundamental resonance. The fitting of the modeled curve based on the estimated lumped parameters with the measured impedance curve is the most reliable way for estimating the resonance frequency and other small signal parameters. 
Diagnostic value	The measurement of the resonance frequency f_s is relatively simple and this value shows • the lower limit of the useable bandwidth of the loudspeaker, • is directly related with the moving mass M_{ms} which directly determines the sensitivity of the loudspeaker in the pass band, • is directly related with the compliance C_{ms} of the suspension and with the displacement of the voice coil. Higher compliance may increase the peak displacement below f_s for a given voltage and may generate rub and buzz distortion at high amplitudes.

2 Measured resonance frequency f_s depends on

Suspension parts	Mechanical Compliance C_{ms} of the drive unit depends on the properties of the spider and surround made of impregnated fabric, rubber, foam and other soft materials. **Recommendation:** Measure the compliance of the suspension parts with a dynamic measurement technique as defined in the IEC standard 62459. Fast measurements can be accomplished in the small signal domain by placing a metal cone of known mass in the inner side of the suspension part and by using a pneumatic excitation. Find an agreement of permissible tolerances for the compliance of the suspension part manufacturer and check this on a regular basis.
Climate condition	The properties of suspension parts strongly depend on climatic conditions such as humidity and temperature. If the temperature rises from –40 °C (–40 °F, for example, a cold loudspeaker in a car during a Canadian winter) to +40 °C (about 104 °F, as in a hot car in Mexico), the compliance may increase by up to 200%, and the resonance frequency may become approximately one octave lower. **Recommendation:** The ambient conditions where the device under test is stored or measured should be controlled at least 24 hours before testing. If this is not possible measure humidity and temperature during end-of-line testing and store those data together with the loudspeaker characteristics and makes it possible to explain the major variation of resonance frequency f_s and allow a prediction of the variation based on simple mathematical model (linear regression).
Ageing of the suspension	The properties of the suspension parts vary with time. Operating a suspension at high amplitudes over some time causes an irreversible rise of the compliance C_{ms} which is well known from long-term power testing after “breaking in”. The resonance frequency of a just assembled drive unit may change in the next hours due to the hardening of the glue. **Recommendation:** Golden reference samples taken some time ago may significantly differ from the devices tested at the end of the assembling line. This difference should be considered in the calculation and recalibration of the limits applied to f_s.
History	The compliance C_{ms} of the suspension decreases for a short time (a few seconds) after having a larger displacement where the microfibres in the woven fabric have changed their position and the viscous properties of the impregnation delay the relocation process. The pre-stress during a large signal measurement (e.g. rub and buzz and distortion measurement, motor and suspension checks) will affect the measurement of the resonance frequency in the following impedance measurement at low frequencies. **Recommendation:** Perform the small signal measurement before the large signal measurements.
Amplitude of stimulus	The peak-to-peak displacement generated by the stimulus affects the variation of the resonance frequency. In the small-signal domain, the geometrical nonlinearities of the suspension are negligible. As the amplitude increases, these nonlinearities become significant and lead to a decrease in the resonance frequency. This effect is closely related to the visco-elastic behavior described in the last section “History”. **Recommendation:** Generate the same peak-to-peak displacement to compare measurements with different stimuli (bandwidth, density of tones, crest factor). The voltage at the loudspeaker terminals is not a sufficient specification to ensure comparable results!
Measurement time	The length of the stimulus used in the impedance measurement affects the variation of the resonance frequency by two ways: • visco-elastic behavior of the suspension: The longer the measurement the larger is the temporary loss of stiffness.

	• Signal to noise ratio: If the measurement time is very short and the excitation amplitude is low, the impedance curve can be distorted by measurement noise, leading to a less accurate estimation of f_s during curve fitting **Recommendation:** There is no time for extensive averaging of the impedance curve during end-of-line testing. If the measurement time is very short (200 ms) the voltage at the terminals should be adjusted carefully to ensure a good signal to noise ratio and to avoid nonlinear distortion.
Waveform of the stimulus	The measured resonance frequency f_s also depends on the spectral and temporal properties of the stimulus: • Resolution: A poor resolution of the measured impedance may produce errors in the fitting algorithm which affects the accuracy of the f_s estimation • Crest factor: The ratio between peak-value and rms-value of the voice coil displacement should be low to avoid nonlinear distortion. • Bandwidth: The resonance should be excited at least one octave below and above the resonance. However, the precise measurement of the parameters (DC resistance R_e, inductance L_e and electrical, mechanical and total Q factors Q_{es}, Q_{ms} and Q_{ts}) requires sufficient bandwidth from $0.1{*}f_s < f < 10{*}f_s$ • Sweep direction: Sweeping the frequency up or down can also affect the results of the f_s measurement. **Recommendation:** Use a stimulus which provides maximal resolution in the measured impedance curve.
Type of stimulus	The sinusoidal sweep with speed profile and the multi-tone stimulus are the most powerful stimuli for measuring the impedance curve at high signal to noise ratio in the shortest time possible: • The multi-tone complex requires a preloop to excite the loudspeaker into steady-state condition. The multitone stimulus measures the impedance at discrete lines at highest precision and may also monitor the nonlinear distortion in the bins of the FFT spectrum which are not excited by the stimulus. • The sinusoidal sweep with speed profile requires no pre-excitation and measures the loudspeaker by using a single transient signal. A low sweeping speed about the resonance frequency ensures high resolution here, which is important for a precise measurement of the small signal parameters. Sweeping upwards is recommended for short stimuli (200 ms) because the transient behavior of the loudspeaker at resonance (high group delay) is still recorded during the sweep generates the following high frequency components. Neither time window should be applied to the electrical impulse response nor smoothing should be applied to the impedance response to sustain maximal resolution of the resonance curve.
Moving mass	Total moving mass M_{ms} is influenced by the weight of the parts and glue used for assembling. **Recommendation:** Measure the mass of the parts on a regular basis.
Calculation method	There are many ways for estimating the resonance frequency: • Searching for the impedance maximum • Searching for the zero phase angle in the complex impedance response • Fitting the measured impedance curve to measured curve predicted by lumped parameter mode **Recommendation:** Specify the method used. The fitting technique provides the highest accuracy even if the impedance curve is corrupted by measurement noise.

3 Example

Target

Practical measurements and statistical investigations are performed and the most interesting results are reported here. The targets of the investigation were

- check the reproducibility and repeatability of the measurement technique (example: Klippel R&D System contra KLIPPEL QC System)
- check the variance of manufacturing process, for example with STAT module
- check influence of the measurement condition on the resonance frequency f_s

Loudspeaker under test

Name	Number of units	Properties
Speaker 1	10	4'' diameter with neodymium magnet
Speaker 2	17	4'' diameter with ferrite magnet
Speaker 3	12	6.5'' woofers with 4 Ω
Speaker 4	12	6.5'' woofers with 8 Ω

Individual-Confidential-Interval (ICI)

In the following, the Individual Confidence Interval (ICI) is analyzed, which is calculated in percent by dividing the 2-σ variance range by the mean value of the parameter under investigation, corresponding to a 95% confidence interval.

Repeatability of the measurement

After repeating all tests, the Intra-Individual-Confidential-Interval (Intra-ICI) for the resonance frequency is calculated. This considers the variation of each device while repeating the measurement under identical or systematically changed measurement condition (e.g. varied voltages). The variation of the resonance frequency between units is excluded. The table below shows the result for a test using a multitone signal of 0.5 s length and a terminal voltage of 0.2 V_{rms} .

	Mean value f_s in Hz	**Absolute Intra-ICI in Hz**	**Relative Intra-ICI**
Speaker 1	110.48	110.37 ... 110.58	**+-0.24 %**
Speaker 2	104.62	104.59 ... 104.65	**+-0.13 %**
Speaker 3	53.52	53.47 ... 53.57	**+-0.43 %**
Speaker 4	59.61	59.53 ... 59.7	**+-0.53 %**

Conclusion: A very small value of the relative Intra-ICI (mean value 0.4 %) is found which shows that resonance frequency f_s can be measured by a short measurement technique.

Production consistency

After that the Inter-Individual-Confidential-Interval (Inter-ICI) for the resonance frequency is calculated, which considers the variation between the different units under identical measurement condition. The variation of the resonance frequency caused by the measurement condition (e.g. varied voltage) is excluded. If the manufacturing process is very stable the Inter-ICI is very small.

	Mean value f_s in Hz	**Absolute Inter-ICI in Hz**	**Relative Inter-ICI**
Speaker 1	110.48	106.44 ... 114.51	**+-3.65 %**
Speaker 2	104.62	103.12 ... 106.12	**+-1.43 %**
Speaker 3	53.52	50 ... 57.04	**+-6.58 %**
Speaker 4	59.61	55.51 ... 63.17	**+-6.88 %**

Conclusion: The Inter-ICI (mean value +- 4.9%) describing the production consistency is about 10 times higher than the Intra-ICI limited by the measurement technique.

Causes for production variances

The variation of the resonance frequency f_s between the units are caused by variation of the moving mass M_{ms} and compliance C_{ms}. The relative Intra-ICI and relative Inter-ICI for M_{ms} and C_{ms} of speaker 3 were calculated by using the laser measurement technique of the R&D System.

	Relative Inter-ICI	**Relative Intra-ICI**
Resonance frequency f_s	**+-6.58%**	**+-0.31%**
Moving mass M_{ms}	**+-5.1%**	**+-1.2%**
Compliance C_{ms}	**+-13.7%**	**+-1.5%**

Conclusion: The high value 13.7 % of the relative Inter-ICI of C_{ms} shows that the main source of f_s variance is caused by the manufacturing of the suspension parts. The relative Inter-ICI of the moving mass M_{ms} of 5.1% is showing that the assembling process is much more stable. The low values in the relative Intra-ICI shows that the laser measurement is still reliable despite the short measurement time used.

Influence of measurement condition

Further tests have been performed while changing systematically one factor and keeping the other factors of the measurement condition constant. The mean relative Intra-ICI describes the impact of the changing factor to the resonance frequency f_s while excluding the differences between the units caused by production variation:

Changed factor	**Relative Intra-ICI**	**Signal**	**Constant conditions**
Voltage in V (0.1, 0.25, 0.5, 1)	**+-3.01%**	Sine sweep up, multitone	f=20-5000Hz, t=0.5s
Time in s (0.2, 0.5, 1, 2)	**+-0.78%**	Sine sweep up, multitone	f=20-5000Hz, U=0.25V
Sweep direction (up-, downwards)	**+-1.91%**	Sine sweep up, sweep down	f=20-5000Hz, t=0.2; 0.5s, U=0.1; 0.5V
Resolution in lines/octave (6, 12, 24, 48)	**+-0.51%**	multitone	t=1s, U=0.25V; 0.5V
Polarity (regular, inverted)	**+-0.24%**	Sine sweep, multitone	f=20-5000Hz, U=0.1; 0.5V
Orientation (top, side, bottom)	**+-1.13%**	Sine sweep up, multitone	f=20-5000Hz, t=0.2, U=0.25
Climate a) 30°C, 46% humidity b) 20°C, 57% humidity	**+-4.05%**	Sine sweep, multitone	f=20-5000 Hz, t=0.5 s, U=0.25 V
History (order of tests)	**+-4.62%**	Sine sweep, multitone	f=20-5000 Hz, t=0.5 s, U=0.25 V
Technique (R&D or QC)	**+- 0,69%**	multitone	t=1 s, U=0.1 V

Conclusion: The voltage, climate and history are the dominant factors causing variation of the measured resonance frequency f_s.

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4 How to define tolerances for f_s

General comments	The discussion in this application note and the results of the practical investigation show that the measured resonance frequency depends on the following main factors 1. total mass M_{ms} of the moving parts including glue used for assembling 2. compliance C_{ms} of the suspension parts 3. climate before and during testing 4. test condition (excitation, orientation) 5. instrument (sensor and data post processing) Only the first two factors (Compliance C_{ms} and total mass M_{ms}) have a direct influence on the perceived sound quality when the device under test is used in the final application.
Correspondence with mass M_{ms}	Variation of the total mass M_{ms} causes not only variation of the bandwidth but also the sensitivity in the pass band. Defining the tolerances L_{SPL_Mean} for the mean SPL level in the pass band and the allowed limits L_{fs} of the resonance frequency the following correspondence should be considered: $$L_{f_s} \approx 10^{-\frac{L_{SPL\_Mean}}{20dB}} * 50\%$$ Here L_{SPL_Mean} is a positive tolerance level of the mean SPL in dB and L_{fs} is a relative tolerance (deviation divided by f_s) of the resonance frequency in percent. For example, an allowed variation of 0.5 dB in SPL mean would correspond with 4.7% variation of f_s.
Correspondence with compliance C_{ms}	Variation of the compliance C_{ms} causes not only variation of the bandwidth but also variation of the peak displacement below resonance. Defining the tolerances L_x for the peak displacement in percent and the allowed limits L_{fs} of the resonance frequency the following correspondence should be considered: $$L_{f_s} \approx \frac{L_x}{2}$$ Here L_x is a relative tolerance (deviation divided by X_{peak}) of the peak displacement X_{peak} in percent and L_{fs} is a relative tolerance (deviation divided by f_s) of the resonance frequency in percent. For example, an allowed variation of 20 % peak displacement would correspond with 10% variation of f_s.
Correspondence with climate variation	The dependency of the compliance C_{ms} and other loudspeaker parameters (e.g. mechanical resistance R_{ms}) on temperature and humidity is caused by the properties of the material used. New material for spider and surround are required to reduce this variation. However, the climate conditions during the end-of-line testing are usually not constant and the tolerances for f_s should be larger than required by other factors. The influence of the ambient temperature can be compensated by performing a recalibration with golden reference units stored under identical conditions. It is recommended to shift narrow limits automatically by using a model which describes the relationship between resonance frequency and temperature.
Measurement condition and instrument	This application note shows that by using a modern measurement instrument and by performing the measurement under optimal and identical conditions (orientation of the speaker, stimulus, sufficient signal to noise ratio, sensitive sensors, signal processing) reliable and reproducible results can be generated even in a very short measurement time (500 ms).

5 More Information

Application Notes and Standards	IEC Standard 62459 "Measurement of Suspension Parts", 2009 Measurement of peak displacement Xmax (Performance based method), Application Note AN4
Related Specification	Linear Parameter Measurement, Specification LPM QC End-Of-Line Test Framework, Specification QC
Manuals	User Manual Linear Parameter Measurement User Manual Quality Control

Find explanations for symbols at:

http://www.klippel.de/know-how/literature.html

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