The lumped parameters of the thermal equivalent circuit are measured by using Power Test Module (PWT). The high-speed temperature monitoring makes it possible to measure voice coil resistance $R_{TV}$ and the capacity $C_{TV}$ of woofers, tweeters, headphones, tele-communication drivers and other transducers having a very short time constant. The regular monitoring with adjustable sample rate also allows to measure the parameters of the magnet and frame having usually a very long time constant. The temperature monitoring is based on the measurement of the electrical impedance at 1 Hz.

CONTENTS:
Thermal Modeling.................................................................................................................. 2
Using the Power Test Module (PWT).................................................................................... 4
Parameter Calculation.......................................................................................................... 5
Setup Parameters for the PRO Module .................................................................................. 7
More Information ................................................................................................................. 8
Thermal Modeling

Equivalent Circuit

The equivalent circuit presented above is used for modeling the thermal behaviors of transducers. This simple model represents the complex temperature field by the mean temperature $T_v$ of the voice coil and the mean temperature $T_m$ of the magnet, pole pieces and frame. This model considers two paths of the heat flow. The main part of the heat goes via the voice coil, pole pieces, magnet and frame to the environment. The second path is the convection cooling transferring the heat from the voice coil directly into the moved air.

We neglect the following processes:

- direct heating of the pole pieces and short cut ring by induced eddy currents
- convection cooling
- distribution of the heat on the voice coil and on the magnet and frame structure

State Variables

- $P_{RE}(t) = i_{rms}^2 R_E$  real electric input power dissipated in voice coil resistance $R_E$
- $i_{rms}$  rms value of input current
- $T_v(t)$  temperature of the voice coil
- $T_m(t)$  temperature of the magnet structure
- $\Delta T_v(t) = T_v(t) - T_a$  increase of voice coil temperature
- $\Delta T_m(t) = T_m(t) - T_a$  increase of the temperature of magnet structure and frame
- $T_a$  temperature of the cold transducer (ambient temperature)
Thermal Parameters

- $R_{tv}$: thermal resistance of path from coil to magnet structure
- $R_{tm}$: thermal resistance of magnet structure to ambient air
- $C_{tv}$: thermal capacitance of voice coil and nearby surroundings
- $C_{tm}$: thermal capacitance of magnet structure

Steady-State Behavior
Applying a stimulus with constant spectral properties the thermal system will go into a thermal equilibrium. Since no heat flows in or out of capacitors $C_{TV}$ and $C_{TM}$ the thermal resistances $R_{TV}$ and $R_{TM}$ determine the steady-state voice coil temperature

$$\Delta T_{vSS} = (R_{TV} + R_{TM}) \frac{P_{RE}}{RE}$$

and the steady-state magnet temperature

$$\Delta T_{MSS} = R_{TM} \frac{P_{RE}}{RE}$$

with $P_{RE}$ is the power dissipated in $R_{E}$.

Dynamics
The variation of the temperature $T_{M}(t)$ and $T_{V}(t)$ versus measurement time $t$ after switching on and off the input power $P_{RE}$ reveals the thermal capacities $C_{TV}$ and $C_{TM}$.

After switching on the input power $P=P_{ON}$ at the time $t=t_{S\_ON}$ the temperature $\Delta T_{M}$ of the magnet increases by an exponential function

$$\Delta T_{M}(t) = \Delta T_{MSS} \left(1 - e^{-\frac{(t-t_{S\_ON})}{\tau_{M}}}\right)$$

to the steady-state temperature $\Delta T_{MSS}$. The time constant of the magnet structure is defined by

$$\tau_{M} = R_{TM} C_{TM}.$$  

After switching off the input power at the time $t=t_{S\_OFF}$ the temperature difference $\Delta T_{V}(t) - \Delta T_{M}(t) = \Delta T_{vSS} - \Delta T_{MSS} e^{-\frac{(t-t_{S\_OFF})}{\tau_{V}}} \right)$

between voice coil and frame/magnet decreases by an exponential function with the time constant

$$\tau_{V} = \frac{1}{R_{TV} C_{TV}}.$$  

Equivalent masses
After determining the thermal capacity of the voice coil $C_{TV}$ we may calculate the equivalent mass of copper by

$$m_{copper} = 2.7 \ C_{TV}$$

where $m_{copper}$ is in gram and $C_{TV}$ is in Ws/Kelvin.

Assuming pure steel for the frame/magnet structure we calculate the equivalent mass of steel by
Principle

For the measurement of the thermal parameters we use a noise signal representing normal audio material as defined by IEC 60268. The measurement is performed by the following steps.

1. In the first step we determine the voltage of the stimulus at the transducer terminals giving a reasonable increase of the voice coil temperature (50 – 100 Kelvin) permissible for the transducer.

2. In the second step we apply the noise at the voltage U and heat up the voice coil and the magnet/frame structure to the equilibrium state.

3. In the third step we activate the high speed temperature monitoring and record the voice coil temperature response after switching off the input power.

4. Based on the measured temperature responses we calculate the thermal parameters

Using the Power Test Module (PWT)

Requirements

The following hardware and software is required for assessing $X_{\text{max}}$

- Power Test Monitor PM 8 + PC
- Software module Power Test (PWT) + dB-Lab

Setup

Connect the microphone to the input IN1 at the rear side of the DA. Set the speaker in the approved environment and connect the terminals with SPEAKER 1. Switch the power amplifier between OUT1 and connector AMPLIFIER.

Preparation

1. Open dB-Lab
2. Create a new object DRIVER based on the template Thermal Parameters AN 18.

Measurement

1. Start the 1st measurement "1st: Find test voltage". During the measurement the amplitude of the stimulus will be increased by 2dB steps after a cycle time of 30 s. If the voice coil resistance is increased to 130 % corresponding to an increase of the voice coil temperature of 80 Kelvin the measured will be interrupted automatically and a exception message "Driver Failure" will be generated.
2. Open the result window "Voltage, Current" and read the rms voltage $U_{\text{TEST}}$ where the voice coil temperature is about 80 Kelvin.
3. Break. The loudspeaker should cool down.
4. Open the property page "Stimulus" of the second measurement "2nd: Parameter Measurement" and enter the starting voltage $U_{\text{Start}}=U_{\text{TEST}}$. Start the second measurement.
5. Open the result window "Power, Temperature". Read the voice coil temperature at the end of the ON-phase. If we get similar values at successive ON-phases the speaker is in thermal equilibrium. After beginning the next ON-phase open the property page "Method". Select the fast speed temperature monitoring to be able to measure the cooling characteristic at high resolution. The temperature measurement in the ON-phase might become more noisy. Under Temperature Window press the button Start to activate the next detailed temperature monitoring at the start of the next OFF-phase.
6. After finishing the OFF-phase the second measurement may be finished.
Parameter Calculation

Steady-State Temperatures

1. Select the second measurement "2nd Thermal Parameters" and open the result window "Power Temperature". Ensure that the driver was in the thermal equilibrium and the temperature has converged to the final value.

Increase of voice coil temperature \( \Delta T_V \) and electrical input power \( P \)

\[
\begin{array}{c|c|c}
\text{t [sec]} & \Delta T_V \text{ [K]} & P \text{ [W]} \\
0 & 0 & 0 \\
500 & 0 & 0 \\
1000 & 0 & 0 \\
1500 & 0 & 0 \\
2000 & 0 & 0 \\
2500 & 0 & 0 \\
3000 & 0 & 0 \\
3500 & 0 & 0 \\
4000 & 0 & 0 \\
4500 & 0 & 0 \\
5000 & 0 & 0 \\
\end{array}
\]

2. Activate the cursor by using the right mouse button and read the temperature of the coil \( \Delta T_{VSS} = \Delta T_V(t_{S\_ON}) \) at the end of the ON-phase \( t=t_{S\_ON} \). Ensure that the driver is in the thermal equilibrium by comparing the \( t_{SW\_ON} \) with the final temperature of previous ON-phases.

3. Use the cursor to read the power \( P_{ON} \) during the ON-phase.
4. Open the result window "Temperature Detail" showing the cooling down response at the beginning of the OFF-phase. The early decay is caused by the time constant of the voice coil. The magnet/frame structure causes a second decay at later times due to the higher time constant. Approximate the early decay by a straight line. Read the early decay time $T_{\text{slope}}$ of the slope. Read the temperature $\Delta T_{\text{MSS}}$ at approximately 5 times of $T_{\text{slope}}$ to ensure that the voice coil is in thermal equilibrium. If the time $T_{\text{sloff}}+T_{\text{slope}}$ is not displayed on the result window "Temperature Detail" use the cursor in the regular window "Power, Temperature" to find $\Delta T_{\text{MSS}}$.

5. Calculate the thermal resistance of the magnet/frame structure

$$R_{\text{TM}} = \frac{\Delta T_{\text{MSS}}}{P_{\text{ON}}}$$

6. Calculate the thermal resistance of the voice coil

$$R_{\text{TV}} = \frac{\Delta T_{\text{VSS}}}{P} - R_{\text{TM}}$$

7. Calculate the temperature where the time constant of the voice coil is elapsed

$$\Delta T_{\text{TAU}_V}(t_{\text{TAU}_V}) = \Delta T_{\text{TV}}(t_{\text{S\_OFF}} + \tau_{\text{TV}}) = 0.37 \Delta T_{\text{VSS}} + 0.63 \Delta T_{\text{MSS}}$$

8. Use the cursor in the result window "Temperature Detail" to read the time $t_{\text{37}}$ where the temperature decayed to $\Delta T_{\text{TAU}_V}$.

9. Calculate the time constant of the voice coil by

$$\tau_{\text{TV}} = t_{\text{TAU}_V} - t_{\text{S\_OFF}}$$

10. Calculate the thermal capacity of the voice coil by

$$C_{\text{TV}} = \frac{\tau_{\text{TV}}}{R_{\text{TV}}}$$
11. Calculate the temperature where the time constant of the magnet is elapsed
\[ \Delta T_{TAU_M} = \Delta T_T (t_{s TM} + \tau_{TM}) = \Delta T_{FSS} - 0.37 \Delta T_{MSS} \]

12. Use the cursor in the result window "Power Temperature" to find the time \( t_{TAU_M} \) where the voice coil temperature is equal to \( \Delta T_{TAU_M} \)

13. Read the time \( t_{S_ON} \) when the time is switched on (with the beginning of the mode GAIN ADJUSTMENT).

14. Calculate the time constant of the magnet by
\[ \tau_{TM} = t_{TAU_M} - t_{S_ON} \]

15. Calculate the thermal capacity of the magnet by
\[ C_{TM} = \frac{\tau_{TM}}{R_{TM}} \]

---

**Setup Parameters for the Template Measurement**

**Template**

Create a new Object, using the object template Thermal Parameters AN 18 in dB-Lab. If this database is not available you may generate an object Thermal Parameters AN 18 based on the general PWT module. You may also modify the setup parameters according to your needs.

**Default Setting for 1st Measurement**

1. Generate a measurement based on the general PWT measurement. Open the PP INFO and call it "1st : Find test voltage". Open the PP STIMULUS. Select internal mode starting at the starting voltage 1 V rms. Enable voltage stepping at size GU 2 dB up to the maximal increase of \( G_{MAX} = 24 \) dB.

2. Open the PP GENERATOR and select noise according IEC60268. Disable high-pass and low-pass filtering.

3. Open the PP CYCLES and set ON-Interval \( T_{ON} = 0.5 \) min.

4. Open the PP METHOD and select Temperature mode and set Number of DUTs to 1. Keep fast temperature monitoring. Select Edit and keep the pilot tone frequency at 2 Hz.

5. Open the PP FAILURE and set the minimal resistance \( R_{min} \) to 10 % and the maximal resistance \( R_{max} \) to 130% corresponding to an increase of the voice coil temperature by 80 Kelvin.
### Default Setting for 2nd Measurement

1. Generate a measurement based on the general PWT measurement. Open the PP INFO and call it "2nd : Parameter Measurement". Open the PP STIMULUS. Select internal mode starting at the starting voltage 1 V rms. Disable voltage stepping.

2. Open the PP GENERATOR and select noise according IEC60268. Disable high-pass and low-pass filtering.

3. Open the PP CYCLES and enable Intermittent excitation. Set the ON-Interval T\textsubscript{ON}= 25 min and the OFF-Interval T\textsubscript{OFF}= 5 min. Set the total measurement time T\textsubscript{TOT}= 3 h and a regular sampling after T\textsubscript{UPD}= 8 s.

4. Open the PP METHOD and select Temperature mode and set Number of DUTs to 1. Use slow temperature monitoring at the beginning of the measurement. Select Edit and keep the pilot tone frequency at 2 Hz. For the result Window "Temperature Window" disable the automatic start but enable the checkbox SYNC with PWT ON/OFF.

5. Open the PP FAILURE and set the minimal resistance R\textsubscript{min} to 10 % and the maximal resistance R\textsubscript{max} to 150 % or other value.

### More Information

#### Literature


#### Software
User Manual for the KLIPPEL R&D SYSTEN.

#### Related Application Notes
“Measurement of Nonlinear Thermal Parameters”, Application Note 19