Operational principle (overview)

The current implementation of the method is based on the cylindrical capacitor placed in the space inside the voice coil former and above the pole piece of magnet system. The inner surface (cylinder) of the capacitor is attached to the top of the pole piece and outer surface inside the voice coil former. Capacitance of this capacitor changes linearly according to the deflection of the cone. Principle of the measurement method and it's utilization in motional feedback is presented at the following figure (Parts added to "traditional" loudspeaker driver are coloured, insulators green, conductors red):

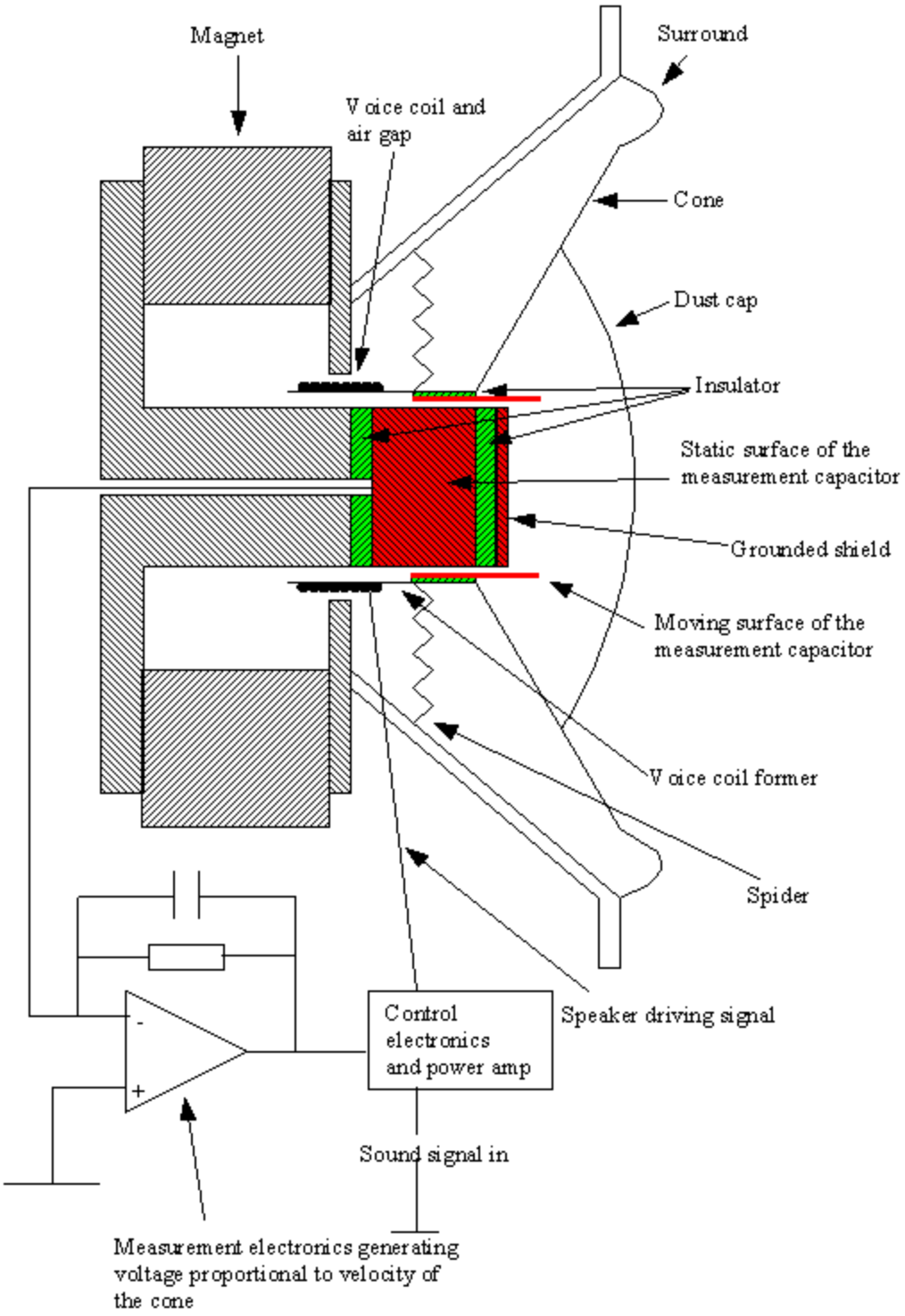

Figure 1: Principle of the measurement method

Capacitance of the measurement capacitor can be calculated using the following formula:

$$C = 2 * \pi * \varepsilon_r * \varepsilon_o \frac{l}{\ln(\frac{r2}{r1})}$$

Formula 1

Where:

εo = permittivity of vacuum (8,8542 * 10^{-12} C^2 * N^{-1} m^{-2})
εr = relative permittivity (for air approximately 1),
l = length of the capacitor (m),
r1 = inner radius of the capacitor (m),
r2 = outer radius of the capacitor (m).

In this formula, the length l is changed according to the movement of the loudspeaker cone. For calculating capacitance per unit of length, following formula can be used (l set to 1):

$$C_m = \frac{2 * \pi * \varepsilon_r * \varepsilon_o}{\ln(\frac{r2}{r1})}$$

Formula 2

Measurement circuit is implemented with simple current to voltage-converter. Providing that the capacitor in operational amplifier circuit is small enough, voltage generated from the circuit is proportional to the change of the capacitance of the measurement capacitor according to following formulas:

$$U_{out} = R * \frac{dQ}{dt}$$

Formula 3

$$U_{out} = R * U_{cap} * \frac{dC}{dt}$$

Formula 4

$$U_{out} = R * U_{cap} * C_m * \frac{dl}{dt}$$

Formula 5

Where:

Uout = output voltage of the current to voltage converter (V),
R = value of the feedback resistor of the current to voltage converter (Ω),
Ucap = voltage applied to the measurement capacitor (V),
dQ/dt = derivative of the charge of the measurement capacitor (As/s (=A)),

dC/dt= derivative of the capacitance of the measurement capacitor (F/s (=A/V)),
dl/dt = derivative of the length of the measurement capacitor (m/s).

With sine signal the deflection of the cone and length of the measurement capacitor follow the following formula:

$$l = x_{max} \sin(f * t)$$

Formula 6

Where:

x_{max} = peak value of the deflection (one way),
l = length of the capacitor,
f = frequency of the sound.

The output voltage of the current to voltage converter can be derived from the formulas 5 and 6 (for sine signal):

$$U_{out} = R * U_{cap} * C_m * \frac{dl}{dt}$$

$$= R * U_{cap} * C_m * 2 * \pi * f * x_{max} * \cos(f * t)$$

Formula 7

So what do all these formulas mean?

Shortly: You get an velocity of the loudspeaker cone from the operational amplifier output terminal. When voltage of around 1kV is connected to the outer surface of the measurement capacitor, the feedback resistor of the op-amp is 1MΩ, excursion of the speaker is +-10mm and frequency 20Hz, you will get output signal of around one volt.

Since the sound generated by loudspeaker is proportional to the acceleration of the cone, either velocity measurement have to be converted to acceleration (by differentation) or sound signal converted to velocity (by integration) to get a comparable signals for the correcting loop.

For more information, construction of the prototypes and measurements read the whole document (PDF, 403 kB).