**Literature Review (for me only)**

The work laid out in [1] describes the derivation of a feedback loop from approximations of the first-order approximations of a loudspeaker. At the resonant frequency of the system, the system’s behaviour is determined only by the unchangeable electrical characteristics of the voice coil, and thus cannot be controlled. At frequencies below resonance, the system has a first-order response, and one proportional-integral (PI) controller is used. At frequencies above resonance, the system has a second order response and two real poles, therefore two PI controllers are used. The controllers take the velocity of the loudspeaker’s cone as an input – there are several ways of deriving this value, since it cannot be done directly. After mentioning the possibility of using an accelerometer or measuring the induced voltage on the voice coil to detect velocity, [1] details a method using a variable capacitance as part of a Clapp oscillator to encode the displacement of the cone using frequency modulation, then using a phase-locked-loop detector to demodulate this value and finally integrating to obtain velocity. The results of the methods used in [1] showcase markedly more linear performance in the sub-500Hz range, with a less substantial roll-off towards the lower extremes of the loudspeaker. Performance above 500Hz remains unchanged. The feasibility of implementing all of the above digitally is also mentioned in [1].

The work laid out in [2] describes a control solution using an accelerometer attached to the cone of a loudspeaker to detect acceleration, and thereby obtaining velocity. The effect of the sensing apparatus is considered on the resulting sound pressure level of the loudspeaker, and was found to be negligible until 1kHz, which is outside the normal operating frequency of a subwoofer, which is the type of loudspeaker being tested upon. The results presented in [2] show that when injecting a 20Hz 8Vrms sinusoid, the total harmonic distortion (THD) is reduced noticeably, by a factor of 2. The acceleration of the cone against time is noticeably less distorted in a time-domain measurement. Results were improved further by the addition of an integrator into the control circuit, which caused a 5-time reduction in THD, and a better open-loop gain.

The work laid out in [4] describes in detail the control mathematics behind the proposed method of deriving an estimate of the cone velocity from the voice coil current, as originally explored by [5]. All of [1,2,4] derive, from the same initial first-order approximation of a loudspeaker, relevant control circuits. [1] describes how a total of 3 proportional-integral (PI) controllers are used to control the first-order response of the loudspeaker below its resonant frequency, and the second-order response of it above its resonant frequency. At resonance, the only parameters that describes the system are the inherent electrical properties of the voice coil, which are fixed. [2] does something.

**Project Initialisation Document**

**Project Description**

The requirements of a loudspeaker as stated by E. R. Hanson [3] are: to be as small as possible, respond as linearly and across as much of the frequency spectrum as possible, to distort minimally, and to consume and emit power efficiently. These aims are almost never completely realised due to nearly all loudspeakers outside of experimental settings not exhibiting any form of feedback mechanisms. The subwoofer is the worst offender in this category; since such large masses of air must be moved to produce low frequencies, the requirements become even more difficult to meet, and poor performance under the 70Hz range [8] is coupled with non-linear and non-ideal performance in the passband. The aim of this project is to explore methods of collecting one or many feedback signals from one or many parameters of a subwoofer and feed them into the input to the voice coil to try and achieve superior sound quality, i.e. more response below 70Hz and linearity, without the expense usually required to purchase open-loop systems that can do so.

**Background Theory**

1. **Loudspeaker Equivalent Circuit and System Block Diagram**

A loudspeaker may be modelled as two circuits, which interact through a magnetic field. The electrical circuit is simply the voice coil’s resistance and inductance. The mechanical circuit is derived through dimensional analysis, which equates the mechanical properties of the mass of the cone and air, the spring property of the suspension, and the total mechanical damping effects as an equivalent inductance, capacitance, and resistance respectively [7]. As shown in Fig. 1(c) [9], these two circuits are linked by a transformer that represents the flux of the magnetic field. The critical relationship of proportionality between force on the cone and current through the coil allows a full system block diagram for a loudspeaker to be derived, as shown by Fig. 1(a) [1,4]. The system analyses conducted by [1] and [4] models the loudspeaker as two systems:

Electrical system = 1/R + sL where R, L are the resistance, inductance of the voice coil respectively.

Mechanical system = s/(k+sb+s^2(m)) where k, m, b are the stiffness, mass, and damping coefficient of the loudspeaker respectively. b = Kf + Zrad where Kf, Zrad are the friction and radiation impedance respectively.

Fig. 1(a) shows that an input signal Vin(s) induces a current I(s) through the impedance of the coil, which enacts an equivalent force F(s) upon the mechanical impedance due to the existence of a permanent magnet. I(s) α F(s) through the force/back-emf constant Bl. The action of F(s) on the mechanical impedance drives the loudspeaker cone with some velocity v(s), which in turn causes a back-emf E(s) to be induced through Bl. E(s) acts against Vin(s).

1. **Thiele-Small parameters**

Manufacturers do not quote

1. **State variable feedback**

As can been seen from Fig. 1(a), the loudspeaker is a single-input single-output (SISO) system. However, there are other potential system outputs that would be valid signals to feed back to the control circuit, such as the current in the voice coil, and some states that cannot be measured directly and thus require the measurement of other parameters to obtain, such as the cone velocity. Thus, the technique of state-variable feedback [11] becomes useful for this project.

1. **Measurements**

The system block diagram shown in Fig. 1(a/b) shows that the cone’s velocity is fed back into a controller, but velocity is not a directly measurable property. The electro-mechanical parameters described earlier must be measured and velocity mathematically derived, or the control loop mathematics adjusted to accept a different parameter as feedback. Some methods of doing so are presented in [1]; the author designs and implements a method using a varactor (variable capacitor) as a displacement sensor. The varactor, as part of a Clapp oscillator, is placed onto the loudspeaker’s cone, and varies in capacitance with the excursion of the cone, generating a frequency-modulated value for displacement of the cone. This varies the frequency of oscillation of the Clapp oscillator, therefore, when, the Clapp oscillator’s output is compared with that of a phase-locked loop circuit [10], the raw displacement measurement is obtained, and a differentiator converts this into the velocity of cone. The full circuit is shown in Fig 2.

The work in [2] describes an accelerometer attached to the cone measuring acceleration.

1. **Subwoofer design**

**Project Specification**

* Theorise, predict, and simulate open-loop loudspeaker behaviour and frequency responses, based on actual subwoofer device parameters.
* Explore different methods of collecting feedback from loudspeaker output and devise a system that combines as many as possible.
* Design and manufacture subwoofer enclosure.
* Design and manufacture control circuits (analogue implementation circuits as minimum, digitally if possible within time).
* Compare performance of subwoofer with and without feedback enabled, and with no feedback systems present in the enclosure at all.
* Qualitatively assess the performance of the finished closed-loop system against a reference high-performance open-loop system.

**Project Schedule**

**Risk Register**

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