The current through loudspeakers when excited with tone-burst signals

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In the discussion regarding voltage- or current-drive of loudspeakers, one of the pro’s of current-drive, usually mentioned, is that it is the *current* which delivers the driving force. This is absolutely true, the question, however, is whether that translates into a correct temporal response of the sound, coming from e.g. bass-reflex loudspeakers. To get a better understanding of these phenomena, the current has been calculated and measured as a function of time when a bass-reflex system is excited with a tone-burst signal from a voltage-drive amplifier.

One of the arguments *against* current-drive is the temporal response, as a bass-reflex system uses resonances to create a “flat” frequency response. However, resonances need time to get started and time to decay. With current-drive, the force is constant when the tone-burst is present and disappears completely once it is finished. The situation with voltage-drive is more complex, so in order to get a better understanding of the phenomena, which govern this process, calculations and measurements have been performed. The calculations are based on the modelled impedance of the woofer section of a bass-reflex loudspeaker, as has been verified in previous work. The measurements are performed using a small (0.11 Ω) series resistor over which the voltage, generated by the current is recorded. Although this gives a slight reduction of the damping factor of the amplifier, it should still be large enough to show the phenomena under study. The major disadvantage is that the signal-to-noise ratio of this signal is rather small, but still sufficient, as will be clear later.

The results of the calculation are shown in fig. 1. The chosen frequency is close to the resonance frequency of the woofer. This, at first rather weird, behaviour can be understood when the phenomena are analysed. An analogy can be helpful to create insight into these. When a car is standing still, a force is required to get it moving. The larger the force, the faster the acceleration and thus a shorter time is required to reach the cruising speed. Once it has acquired speed, a constant force is needed to keep it moving. At the end of the ride, it needs to be stopped, but it will not come to a standstill immediately, but the harder the brakes are pushed, the shorter the time and distance required to come to a standstill. When also engine retarding is used, this goes even faster. The longest time and the longest distance will be needed when only the clutch is pushed (or the gearbox is put in ‘neutral’, so no more force is provided) and the car is left to itself to slow down. Similar phenomena happen with a bass-reflex system: at the start of the tone-burst, the loudspeaker is in rest and in order to get it moving a.s.a.p., a large force is required. With voltage-drive, the current in the initial cycle is the largest (see fig. 1) and it gradually diminishes to a constant level. So the acceleration is initially larger to get the loudspeaker up to its “cruising” speed, after which the driving force can be reduced to a constant level. The current is measured on a full-range bass-reflex loudspeaker, also close to the resonance frequency of the woofer, which is 70 Hz in this case. The result is presented in fig. 2 and although the conditions are only similar and not identical, there are differences, but several characteristics clearly show up in both results.

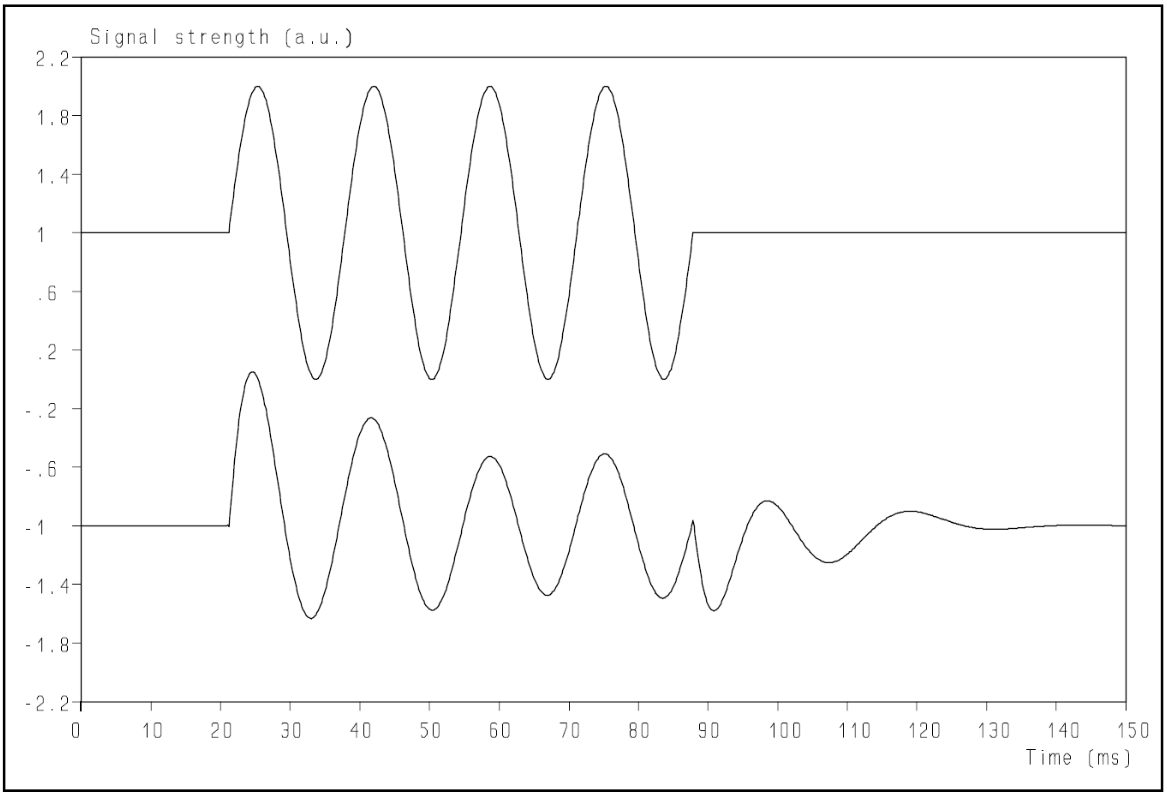

Figure 1: *Calculated current through the bass-reflex when voltage-driven. Exciting frequency = 60 Hz. Upper trace: exciting voltage, lower trace: current through the loudspeaker.*

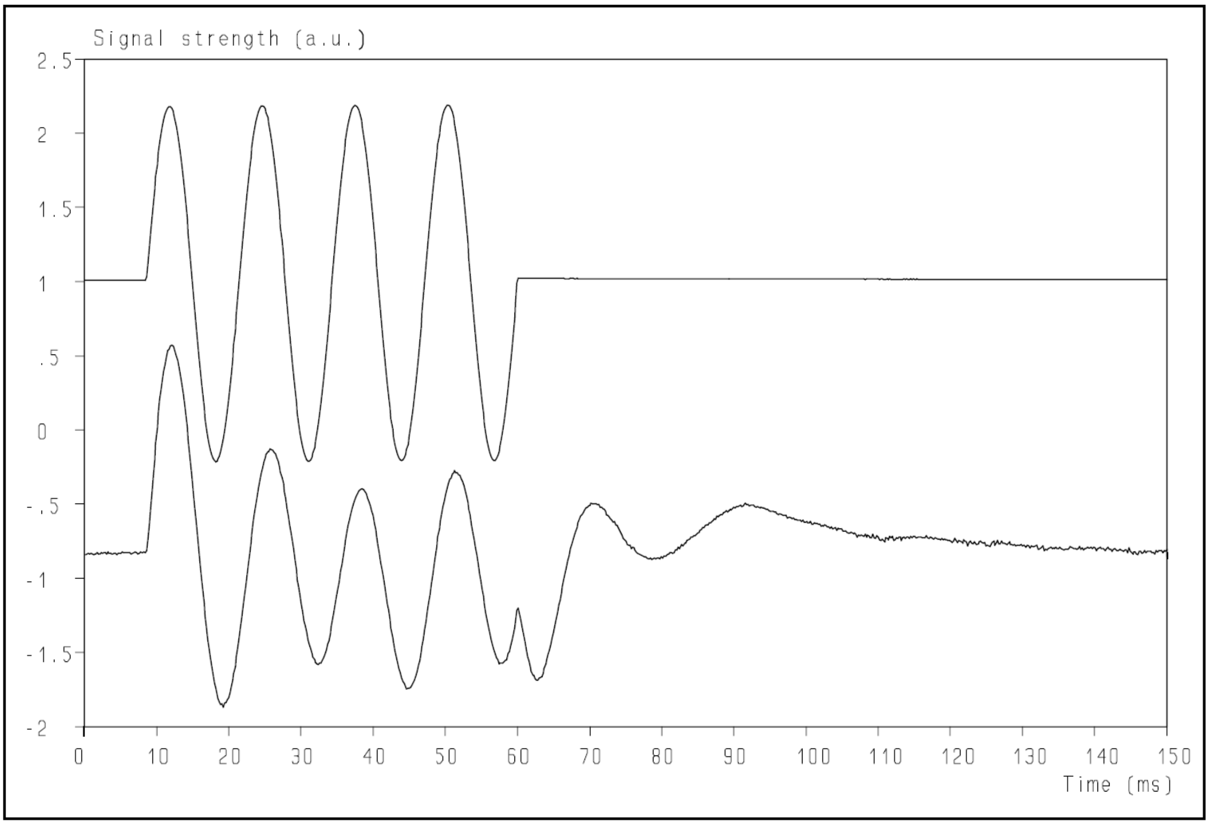

Figure 2: *Measured current through the bass-reflex when voltage-driven. Exciting frequency = 70 Hz. Upper trace: exciting voltage, lower trace: current through the loudspeaker.*

The start of the tone-burst is faster with a voltage-drive than it is with a current-drive (note that the upper traces of figs. 1 and 2 also represent the current with a current-drive). In the perfect system, the loudspeaker would be at full speed as soon as the tone-burst starts. This, however, cannot be achieved with systems, which use resonances. Yet, the voltage-drive performs better in this respect than a current-drive.

The opposite problem occurs at the end of the tone-burst: the loudspeaker should come to a full stop a.s.a.p. With a current-drive, the loudspeaker is left to its own as there is no longer a driving force, but no brake either, similar to the situation when the clutch in the car is pushed. With voltage-drive, however, the moving loudspeaker generates a voltage, which generates a current, back into the amplifier, as is shown both in fig. 1 and 2. This marks the -at first sight- weird inversion at the end of the tone-burst, which generates a braking force, which slows down the loudspeaker, which comes to rest a lot faster than with current-drive, when it is left to itself and continues to produce sound when the tone-burst has already stopped. Note that these phenomena create a delay of the reproduced tone-burst, looking at its centre of gravity, and a time-smear, looking at the envelope of the reproduced signal, compared to envelope of the exciting tone-burst. Both phenomena are undesirable (diplomatically put) for high-end audio systems and thus should be avoided as much as possible. Neither voltage- nor current-drives are able to do this completely, but a voltage-drive comes closer than a current-drive. The only proper way is, of course, to eliminate all resonances to create "flat" frequency responses.

The conclusion is that voltage-drive creates less time delay and less time-smear than current-drive, which is in complete agreement with findings from many sources. In my view, this makes current-drive systems unattractive and I am not surprised that no commercial systems, available for the consumer, are on the market, which are based on this concept.

In reality, no system is a perfect "voltage-drive" or "current-drive". But it is clear that the larger the output impedance of an amplifier, the more it will show the unattractive temporal properties (and coloration!) of current-drive amplifiers. So the larger the output impedance of an amplifier, the more artefacts it will introduce with loudspeakers which employ resonances to create "flat" frequency responses (which, unfortunately, most commercial loudspeakers do).

Similar calculations and measurements have been made at the resonance frequency of the port (figs. 3 and 4) and above both resonance frequencies (figs. 5 and 6). At these frequencies, the characteristics of the current are in reality even more weird than calculated. This can partly be due to the presence of a cross-over filter and partly by the series resistor. But the main properties / artefacts show up in both the calculations as in the measurements. Note that the calculations only use the (idealized) impedance of the woofer section of the loudspeaker, so it can be concluded that the resonances large introduce severe artefacts in the temporal response of the loudspeaker.

The main conclusions are:

- The impedance describes the essential properties (and thus artefacts) of bass-reflex loudspeakers, it is not necessary to add additional parameters to reveal these.
- The measured properties of the current during the presence of the exciting tone-burst show that the voltage drive results in less time delay and time smear of the response than a current drive.

- The measured properties of the current show that (most likely) the response of the cross-over filter introduces additional irregularities during the “on” phase of the tone-burst.
- The loudspeaker acts as a generator once the tone-burst is stopped and “pumps back” current into the amplifier. However, an amplifier is not designed for this, resulting in additional distortion. Impedance compensation can reduce this phenomenon significantly and it is therefore highly recommended.

These results clearly underpin the requirement to eliminate all resonances in a “high-end” audio system to create “flat” frequency responses as these ruin the temporal properties of the reproduced sound, resulting in must-to-avoid artefacts.

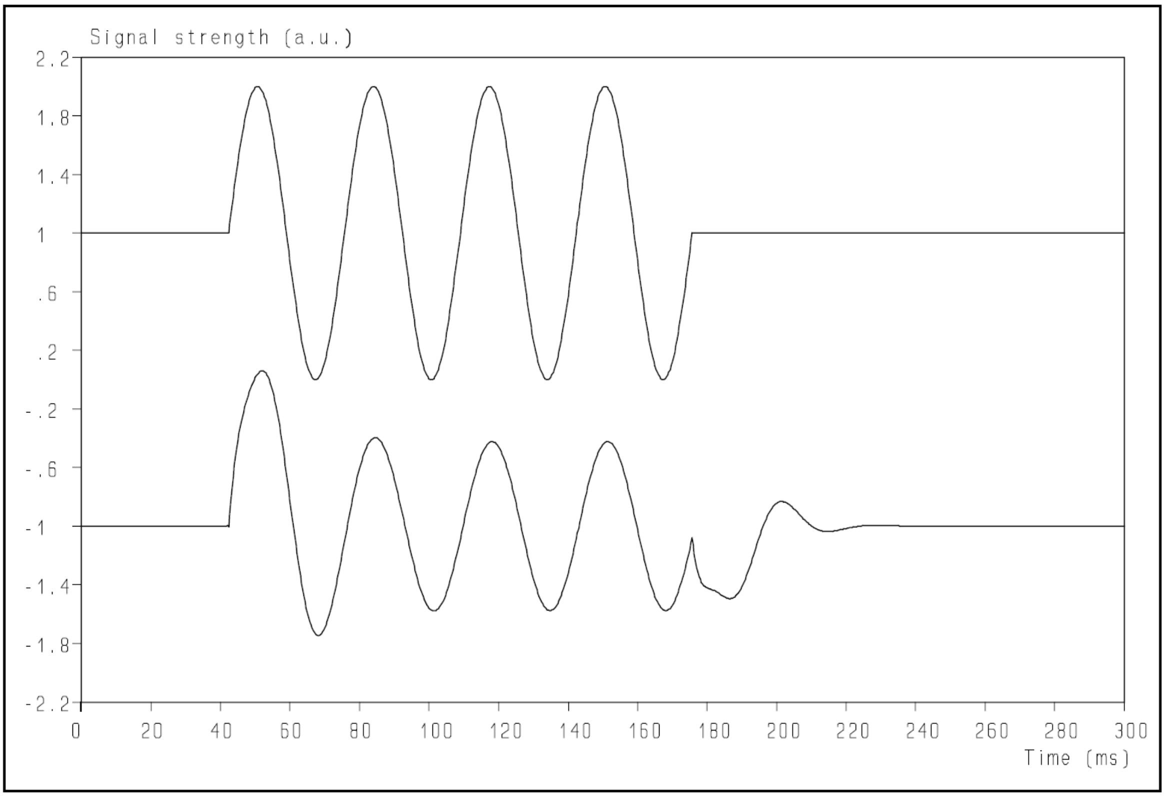

Figure 3: *Calculated current through the bass-reflex when voltage-driven. Exciting frequency = 30 Hz. Upper trace: exciting voltage, lower trace: current through the loudspeaker.*

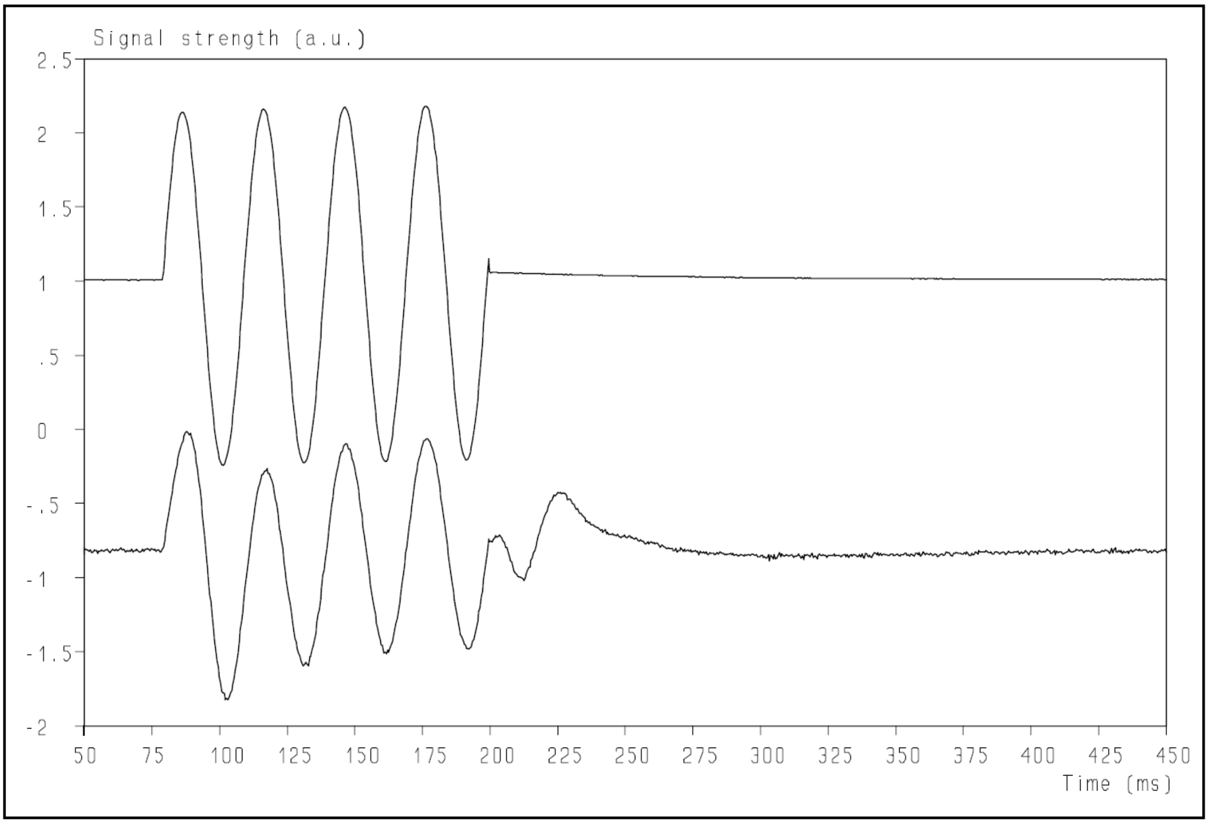

Figure 4: *Measured current through the bass-reflex when voltage-driven. Exciting frequency = 30 Hz. Upper trace: exciting voltage, lower trace: current through the loudspeaker.*

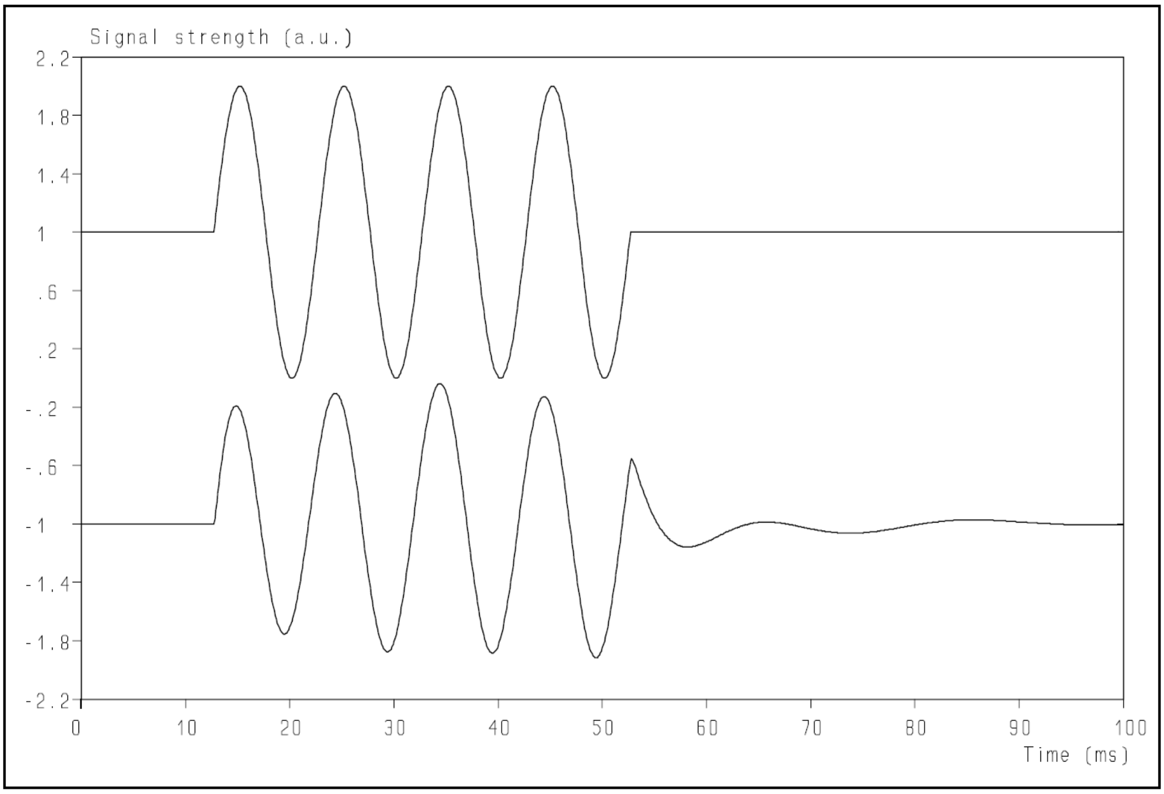

Figure 3: *Calculated current through the bass-reflex when voltage-driven. Exciting frequency = 100 Hz. Upper trace: exciting voltage, lower trace: current through the loudspeaker.*

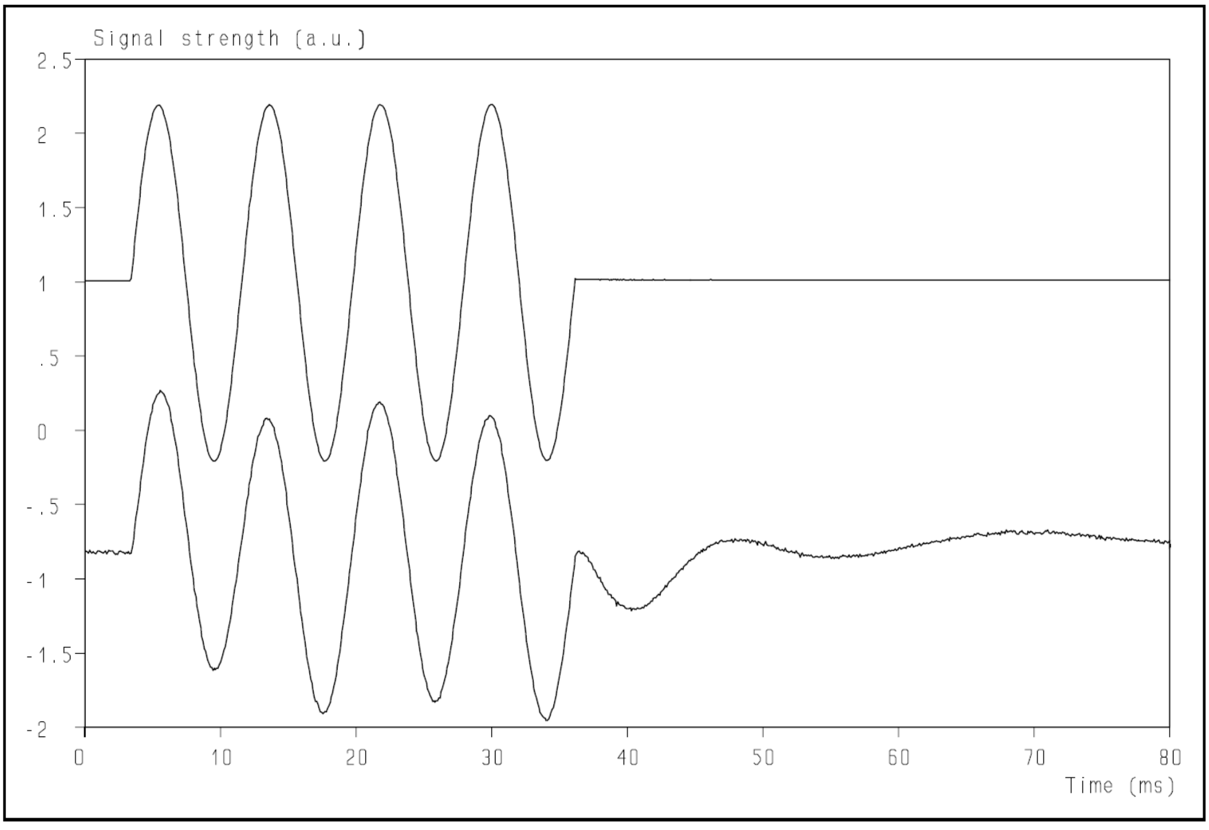

Figure 6: *Measured current through the bass-reflex when voltage-driven. Exciting frequency = 110 Hz. Upper trace: exciting voltage, lower trace: current through the loudspeaker.*