Loudspeaker operation: The superiority of current drive over voltage drive

Esa Merilainen -October 22, 2013

This is an overview of the destructive effects that voltage drive has on the performance of electrodynamic loudspeakers. A more comprehensive treatment of the subject can be found in the book ***Current-Driving of Loudspeakers: Eliminating Major Distortion and Interference Effects by the Physically Correct Operation Method*** by Esa Meriläinen.

Today, practically all available audio amplifier and loudspeaker equipment works on the voltage drive principle without significant exceptions. This means that the power amplifier acts as a voltage source exhibiting low output impedance and thus strives to force the voltage across the load terminals to follow the applied signal without any regard to what the current through the load will be.

However, both technical aspects and listening experiences equally indicate that voltage drive is a poor choice if sound quality is to be given any worth. The fundamental reason is that the vague electromotive forces (EMF) that are generated by both the motion of the voice coil and its inductance seriously impair the critical voltage-to-current conversion, which in the voltage drive principle is left as the job of the loudspeaker.

The driving force (***F***), that sets the diaphragm in motion, is proportional to the current (***I***) flowing through the voice coil according to the well known formula ***F*** = ***BlI*** where the product ***Bl*** is called force factor (***B*** = magnetic flux density; ***l*** = wire length in the magnetic field). ***B*** is the flux density that exists when the current is zero. (The current always induces its own magnetic field, which may react with adjacent iron, but the effect is not related to this equation.)

This force, then, determines the acceleration (***A***) of the diaphragm, which in the main operation area (the mass-controlled region) is got from the Newtonian law $\boldsymbol{F} = \boldsymbol{mA}$. The radiated pressure, in turn, follows the instantaneous acceleration and not the instantaneous displacement, as many mistakenly imagine.

The most remarkable thing here regarding loudspeakers is that the voltage between the ends of the wire does not appear anywhere in these equations. That is, the speaker driver in the end obeys only current, not caring what the voltage across the terminals happens to be.

There cannot be found any scientifically valid reasons that justify the adoption of voltage as the control quantity - it is only due to the historical legacy originated almost a century ago, most likely by cheapness and simplicity; the quality and physical soundness of operation have not been considerations in this choice. Engineers are also more accustomed to identifying electrical signals as voltages rather than currents.

At least the hi-fi community should be interested and able to better see through this discrepancy. But they too have taken the state of affairs as a given, being largely conditioned to the wishful thinking that tightly held voltage somehow "controls cone motion," even up to middle and high frequencies. Such a notion doesn't have real scientific grounds, and it can be clearly shown by basic analysis and modeling that any damping effects that voltage drive can have on driver operation are strictly limited to the bass resonance region.

The components of impedance

The electrical equivalent circuit of a moving-coil drive unit can be depicted as the series connection of a resistor and two voltage sources, as shown in Figure 1. $\boldsymbol{R_c}$ represents the voice coil DC resistance; voltage source $\boldsymbol{E_m}$ represents the motional EMF (so-called back-EMF) of the driver and is calculated by $\boldsymbol{E_m} = \boldsymbol{BlV}$ ($\boldsymbol{V}$ = voice coil velocity); and voltage source $\boldsymbol{E_i}$ represents the inductance EMF that is generated by the lossy inductance of the voice coil. This is the proper end essential representation of the electrical system for examining the amplifier-speaker interface. Any wiring resistances and possible output resistance of the voltage amplifier simply add to $\boldsymbol{R_c}$ and thus don't need any specific attention.

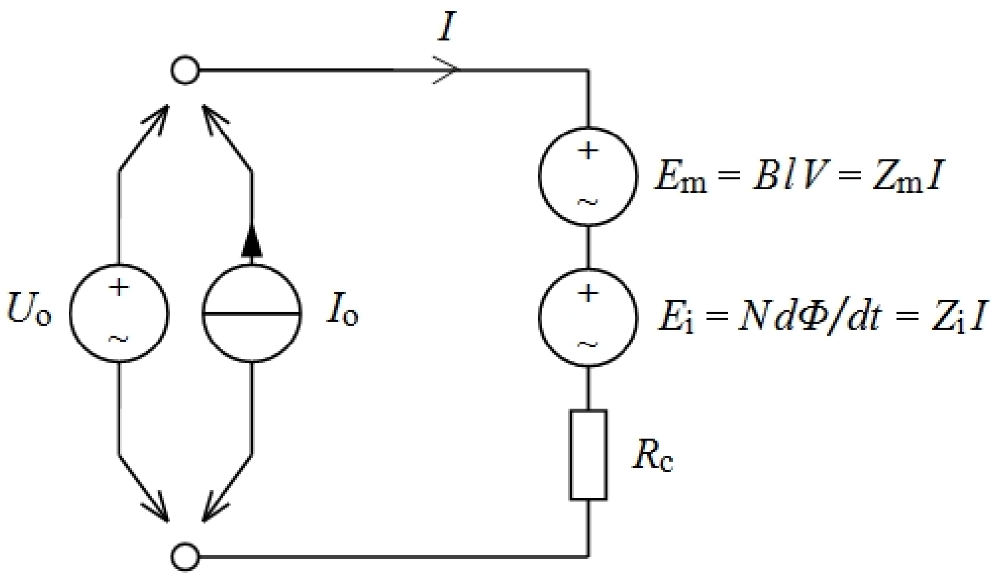

Figure 1: The electrical equivalent circuit of a moving-coil transducer with two kinds of feeding sources.

Both $\boldsymbol{E_m}$ and $\boldsymbol{E_i}$ are subject to a multitude of disturbances that corrupt the flow of current when the circuit is fed by a voltage source ($\boldsymbol{U_o}$). Thus the magnitudes of these two are of utmost interest. When the feed comes from the current source ($\boldsymbol{I_o}$), $\boldsymbol{E_m}$ and $\boldsymbol{E_i}$ only appear as additional voltages in the amplifier output, having no influence on the current.

In the impedance modulus curve of a typical moving-coil driver ($|\boldsymbol{Z_{tot}}|$ in Figure 2), $\boldsymbol{E_m}$ manifests itself as the high peak at the resonant frequency, while $\boldsymbol{E_i}$ is responsible for the gradual rise typically starting in the whereabouts of 300 Hz. When looking at such a curve, one can easily be mistaken to assume that $\boldsymbol{E_m}$ is significant only near the fundamental resonant frequency or that $\boldsymbol{E_i}$ is significant only at the highest operating frequencies. In reality, however, these two components are of almost opposite phase in the midrange and therefore largely mask each other near the impedance minimum.

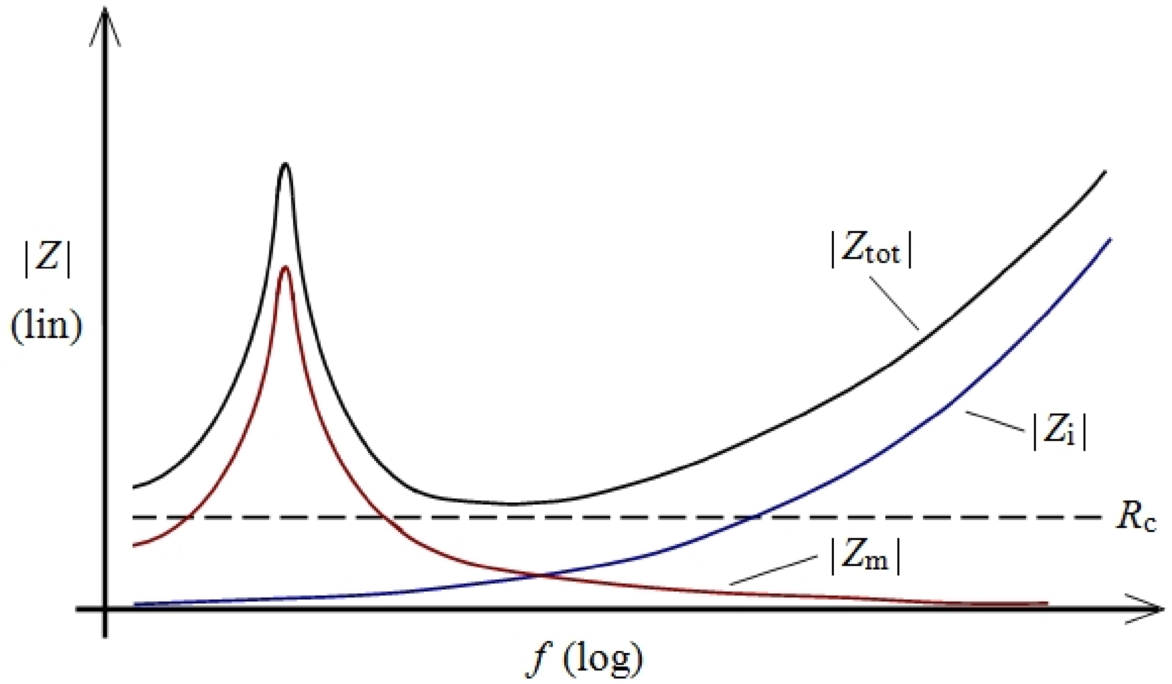

Figure 2: Composition of the impedance magnitude curve of a typical cone driver. Both the motional impedance Z_m and the inductance impedance Z_i have considerable magnitude throughout the main operation area.

Figure 2 thus also shows the actual and typical magnitudes of the impedance components separately, which are also measurable by special techniques. It is seen that the sum of $|\boldsymbol{Z_m}|$ and $|\boldsymbol{Z_i}|$ is in fact in the whole operation band at least of the same order of magnitude than $\boldsymbol{R_c}$. Increasing driver efficiency also increases both $|\boldsymbol{Z_m}|$ and $|\boldsymbol{Z_i}|$.

Next: Basic low-frequency operation

24 Comments

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TedC

No speakers is actually driven from a voltage source anyway, they're driven through a complex passive network that used to be the crossover but which is now a compensator also.

Aug 2, 2016 12:42 PM EDT

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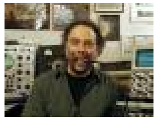
Reply



Michael Dunn

Lots of speaker drivers are driven from a voltage source. E.g., in my own bi-amped, electronically crossed-over boxes. And many professional studio monitors...

Aug 2, 2016 2:04 PM EDT

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Reply

TedC

A speaker will sound best when driven from the source impedance it was designed for.

Aug 2, 2016 12:39 PM EDT

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Reply

bcarso

Having obtained the book, I strongly recommend it.

Brad

Feb 9, 2014 2:29 PM EST

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Reply

Mark Spellman

Current drive of speakers was actually quite common back in the day of pentode output stages with no feedback. This was typical of "all American" five tube radios and low priced record players. With the pentode's high output impedance (AKA current source), the rising impedance of the speaker at high frequencies caused an unwanted treble boost which was compensated for by adding a "tone condenser" across the primary of the output transformer.

I agree about damping factor being a load of nonsense.

My theory is that it was popularized by solid state amplifier marketers in the 1960s who wanted a number to "prove" the superiority of their product.

Oct 30, 2013 2:08 PM EDT

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Reply

timofey

You are right, tube amplifiers have high output impedance and produce a different sound with the same loudspeakers. In my country in seventies there was a special term - "transistor sound" stressing that the same loudspeaker usually sounds worse when it is driven from a semiconductor (i.e. voltage-feedback) amplifier. The new usually turns out to be something old but forgotten. The first article offering "current drive" of loudspeakers I saw about 30 years ago. As usual - the new turns out to be the old but forgotten.

Oct 31, 2013 1:46 AM EDT

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Reply

JeffL_2

Oh and one more thing, applying negative feedback around an amplifier to reduce distortion has the mathematical tendency to LOWER the output impedance. This would mean the last voltage-to-current conversion stage would have to operate without benefit of negative feedback to remain a high-impedance current source, so the measured distortion level of such an amplifier would be higher, not generally a desirable situation in an audio system.

Oct 25, 2013 7:01 PM EDT

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Reply

Esa Merilainen

In current-output (transconductance) amplifiers, the feedback represents the current flowing through the load and thus increases the output impedance while reducing distortion similarly as with voltage feedback. The two forms of feedback can also be mixed to adjust the output impedance.

Yes, for a given load impedance and signal level, current-drive needs some extra voltage margin especially with highly complex loads; but on the other hand, the peak current demand is correspondingly lower and precisely known.

Applying pure current-drive for existing voltage speakers is not so advisable due to frequency response alteration. Speakers naturally have to be designed for the concept, preferably beginning from the drivers.

Oct 26, 2013 1:27 PM EDT

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Reply

JeffL_2

If I think really hard I do remember seeing current feedback applied around a transconductance amp once upon a time but that was DECADES ago (!), I'm pretty sure the application was a torque motor drive so I'm sure the topic of "distortion" never came up. The premise of applying large amounts of feedback around a load with a highly complex reactance is bad enough, include varying amounts of back EMF and I have a feeling you'll have a hard enough time trying to "establish" stability, may not leave you with enough "degrees of freedom" to worry much about how much the feedback improves linearity. (I don't recall even seeing a bipolar OTA between the time I saw that old circuit and now, all I seem to run into are unipolar adaptations on the theme of current mirrors.) I'll more than accept that your "premise" is correct (in fact it HAS to be) but like you were hinting at the difficulty is in making it work. Also if you have to drive a loudspeaker coil through an essentially undamped resonance impedance peak you WOULD need all kinds of compliance to keep the current going, so I think the concept really makes more sense in something like a powered speaker system. Thanks for the comment.

Oct 26, 2013 2:21 PM EDT

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Jacec

You can build a spice simulation circuit and check that this story is simply untrue. The distortions lower regardless of feedback type. I use currently Esa M. invented audio set and it cannot be compared with even the best traditional sets (it resembles little bit old tube radio sound but it is far

better)
Jacek

Mar 14, 2014 5:38 PM EDT

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Simon7382

Unless of course one applies current feedback instead of voltage feedback which actually increases the output impedance.

Dec 18, 2015 10:28 PM EST

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JeffL_2

All well and good, but if you consider primarily analog amplifier implementations and you require that the compliance voltage available to the cone's transducer be relatively high, the electrical efficiency becomes low and you wind up wasting lots of power in the pass devices a bit problematical when you're trying to deliver a kilowatt or more for doing sound reinforcement for an arena. This would also create havoc in any existing system with passive crossovers designed for voltage supply. Maybe someone besides myself remembers the old transformer-based "25 volt" and "70.7 volt" distribution systems (all long out of service I suppose), they wouldn't work either (again not a big issue, just showing why things are like they are). I'm not sure how you could design an efficient digital PWM-based current drive, maybe someone can provide a circuit or reference for review?

Oct 25, 2013 3:27 PM EDT

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Reply

EMCgenius

25 and 70.7 volt systems are alive and well, but generally not seen in consumer equipment. These standards are used in public address systems, which is a different world.

Oct 29, 2013 1:15 PM EDT

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Reply

JCreasey

I think there are complexities with both voltage and current drive (and we certainly have gotten good at compensating for them in amplifier design) that could be corrected with direct motional feedback. Philips championed this in the 70's and with today's SOCs, accelerometer sensors, new cone materials and rare earth magnets it should be possible to visit this again and produce much better low distortion mid/low range loudspeakers at reasonable costs.

Oct 24, 2013 2:10 PM EDT

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Reply

timbalionguy

This is interesting, and may explain a significant difference I heard in a demonstration of different kinds of opamp-based headphone drivers. One opamp system was a traditional voltage system, the other a 'transconductance' system, if I recall.

Damping factor does help, and I have heard the audio quality improvement that happens when you drive a simple, relatively inexpensive loudspeaker system with a very large power amplifier.

This may also explain the good sound obtained from planar and plasma speakers, where the inertial mass of the driver is negligible.

But at the end of the day, I suspect that current drive will have its limitations and idiosyncrasies as well. There is no 'free lunch' when driving something as electromechanically complex as a loudspeaker.

What may be needed is some sort of mechanical feedback to tell the amplifier what the speaker is doing, and to correct it as needed. This has been tried before, and was marketed as a brand of (professional entertainment) speaker called 'servo drive'. I am told that these speakers had remarkable performance (apparently, especially for bass), but a few folks did not like how they sounded.

Oct 23, 2013 5:33 PM EDT

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Reply

Douglas.Butler

When I was in college about 1980 there was a large speaker in the acoustics lab that used a high frequency LVDT for closed loop position control of the cone. I never heard it but I was told it performed well physically but "sounded terrible".

Oct 30, 2013 8:13 AM EDT

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Reply

Rosalfonso Bortoni

Current-driven loudspeakers, when well designed, are indeed superior over the voltage-driven ones.

I would suggest the reading of this paper "Effects of Acoustic Damping on Current-Driven Loudspeakers," **http://www.aes.org/e-lib/browse.cfm?elib=14058,** and its references.

Also, Professor Hawksford has worked on this subject a long time ago, **http://www.essex.ac.uk/csee/research/audio_lab/malcolms_publications.html.**

Oct 23, 2013 4:42 PM EDT

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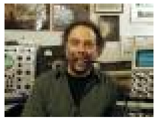
Reply



Michael Dunn

For a given driver, designed to be as flat as possible under voltage drive, wouldn't the frequency response get messed up using current drive?

Oct 22, 2013 9:50 PM EDT

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Reply

catraeus

Exactly, Michael! These are all linear phenomena. It is all about equalization. The speaker has significant power converted to audio energy (the point, of course) which is the transduction from electrodynamic to acoustic domains. This power transduction has a transfer function vs. frequency which has been accommodated (over the course of the very same century) to produce some very fine sounds.

In my opinion, the majority of distortion is due to the excursion of the cone and its mechanical framework leading to these non-linear effects.

Oct 23, 2013 4:36 PM EDT

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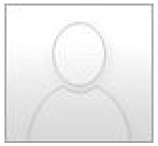
Reply



emover

And that is precisely the problem. The creation of pressure waves from typical loudspeaker is only a linear function during small excursions and the system has mechanical dampening built in. Fluid function changes and atmospheric variables will create an active impedance match between the motor and the air. The effect can be a voltage standing wave reflection that could be difficult for a current source amplifier to stabilize (reactive EMF from normalizing the EM field). I agree that BLV = ZmI in an unloaded system, but not in a reactive enviroment.

Oct 30, 2013 3:20 PM EDT

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Reply

Amcfarl

I understand that Linn Products in the UK make (or made) a super-woofer with current drive and an accelerometer mounted on the cone to give feedback. Maybe someone has some info as to how well this worked?
NB the references to Bortoni et al do not work

Oct 30, 2013 3:45 PM EDT

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Reply

Jacec

In current-driving amp typically is in use a feedback resistor in series with load.

Action of this resistor can be compare to ‘accelerometer’.

Mar 15, 2014 5:57 PM EDT

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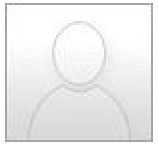
Reply



bcarso

Yes, agree with catraeus. Although there could be advantages to current drive, such as the near-elimination of voice-coil resistance-change effects with signal-induced self-heating, usually to take advantage of this requires that the loudspeaker has been developed using said current drive --- which no one does, at least for stand-alone loudspeakers. Otherwise simply applying current drive to a voltage-drive-derived loudspeaker is near-madness, and will result in huge frequency response anomalies.

There are several reasons for the nonlinear distortions in loudspeakers, including the suspension and airmass-loading departure from a linear relation of drive and displacement, and the change in the motor characteristic with displacement. At higher frequencies the sensitivity will change as a function of voice coil position in the gap as well, but here the higher frequencies are not themselves moving the cone so much, but rather the sensitivity modulation from the low-frequency displacement entails intermodulation distortion. And IM distortion is by far the more audible and obnoxious effect, more likely to produce byproducts that are unconcealed by other desired material.

Of course another reason for the absence of significant current drive applications is the relative unfamiliarity of engineers with techniques of realizing it. But it can be done, and as Bortoni references, has been explored.

Timbalionguy mentions servo control, and indeed this is a valid and useful approach to reducing nonlinear distortions in woofers. An extension of this is to map the sensitivity as a function of displacement, for a broadband transducer, to the mids and highs, and "back out" the modulation effects. Many are the ways.

Brad

Oct 24, 2013 1:04 AM EDT

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Reply

Esa Merilainen

Besides the low-frequency implementation, that must be thought anew for current-drive, there is the obvious difference in responses that follows the driver's impedance curve. The response rises towards high frequencies when the voice coil inductance is no longer low-pass filtering (and also messing up) the current. The book also discusses various methods to compensate this effect in passive speakers where it can be an issue. In high-frequency units, the rise is often even beneficial, as the upper band limit can be pushed higher, and the power response becomes more even.

Oct 24, 2013 11:24 AM EDT

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Reply

such thing as too much

Appliance autonomy promises to make life simpler

Bad-bulb finder fixes Christmas lights

Teardown: WeMo Switch is highly integrated

>> Chip Fuse Protects Against Excessive Temperature & Overcurrent

>> Know the Difference Between an Inverter, Converter, Transformer and Rectifier

>> Dual Channel 4A, 42V, Synchronous Step-Down Silent Switcher 2 with 6.2μA Quiescent Current