Proceedings of the Institute of Acoustics
Illustrated revision, May 2019

ORBITSOUND

SUPERIOR HIFI SOUND

E Fletcher Fellow of the Faculty of Arts (hon) University of West London. President, Orbitsound
D Fletcher BSc (hons), Technical Director, Orbitsound

Ted Fletcher
President, Orbitsound

Daniel Fletcher
Technical Director,
Orbitsound

1 ABSTRACT

At Orbitsound we have been working with and continually developing Airsound (point source stereo). More recently, our focus of development has been creating high-fidelity listening with Airsound coupled with investigations into the advantages of current-drive for loudspeaker drivers. This paper and live demonstration gives a basic introduction to the transconductance amplification principle as a means to achieve better realism in reproduced sound.

The practical demonstrations include an A/B comparison of transconductance amplification (all else being equal). There will also be a demonstration of a super high-end loudspeaker system with multiple transconductance amplifiers, currently in prototype form.

2 INTRODUCTION

Ted Fletcher made his first transconductance amplifier in 1976 as a means of driving a talkback loudspeaker for a BBC continuity mixing desk with great success in improved clarity of speech. In 1995 Ted made a modified high-power amplifier that worked in this current mode and went on to experiment with other applications of current mode thinking. Ted has been thinking about transconductance for over 40 years.

Ted is not alone. Other electronics engineers have created numerous specialist circuits that achieve remarkable things through current mode thinking. Such circuit developments include CRT display alignment, hearing aid loop systems, aspects of telephony, low current hearing aid processors and many more diverse applications.

At Orbitsound over the past two years, we have been working with transconductance as a logical and important step in improving our own loudspeaker systems. Some systems are approaching production and will be available for the first time during 2019 on general release.

Original Publication: Vol. 40. Pt. 4. 2018

3 MATHEMATICAL LANDSCAPE

3.1 Definitions

An amplifier is a device that multiplies an input signal's voltage by some gain factor and produces this as its output voltage. A 'good' amplifier will achieve an output voltage directly proportional to the input voltage.

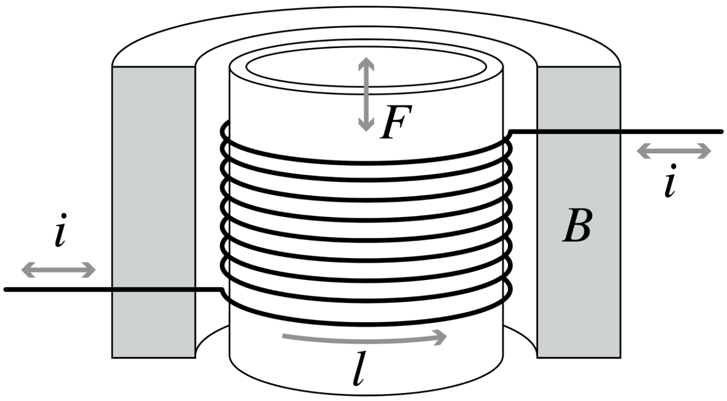
"Transconductance is the electrical characteristic relating the current through the output of a device to the voltage across the input of a device." Wikipedia, October 2018. A Transconductance amplifier is an amplifier who's output current is some a function of the input voltage signal.

For both kinds of amplifier, a 'good' amplifier maintains a consistent gain across useful frequency ranges (frequency response), and reproduces only the input signal (low noise & distortion).

3.2 Moving Coil Loudspeakers

A Loudspeaker is a current carrying coil that is suspended in a strong magnetic field. This coil is attached to a diaphragm which moves air in a way that we hear. The motive force is:

Founding Principle, BLI Law



$$F=Bli$$

The force (F) experienced by a driver diaphragm is the magnetic flux density (B), multiplied by the length of wire contained in the field (l), multiplied but the current (i) of the electrical signal.

This force is converted into sound that we hear by Newton:

$$a = \frac{F}{m}$$

The driver acceleration is given by the net of forces divided by the driver's mass. Acceleration can be integrated to give the driver's velocity, and integrated again to describe the driver's motion or displacement.

The only electrical factor in determining the motive force for a loudspeaker cone is the current passing through the voice coil. All other factors are mechanical.

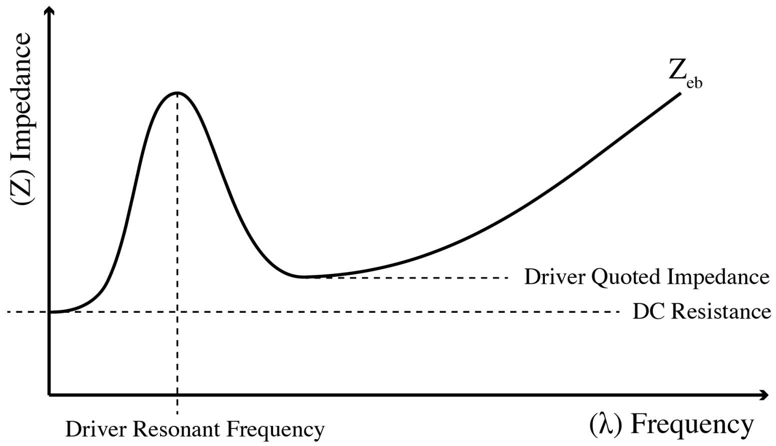
4 AMPLIFIERS & LOUDSPEAKERS

4.1 Amplifier-Loudspeaker Coupling

The amplifier output voltage can be converted to (i) current by the equation:

$$i = \frac{v}{Z}$$

Z is the driver's electrical impedance and is amongst other things, frequency dependent. For a driver in free air, typically looks like this:



The impedance of the driver changes with frequency. But there is much more still to (Z). A more complete equation to relate the force on the loudspeaker driver cone is:

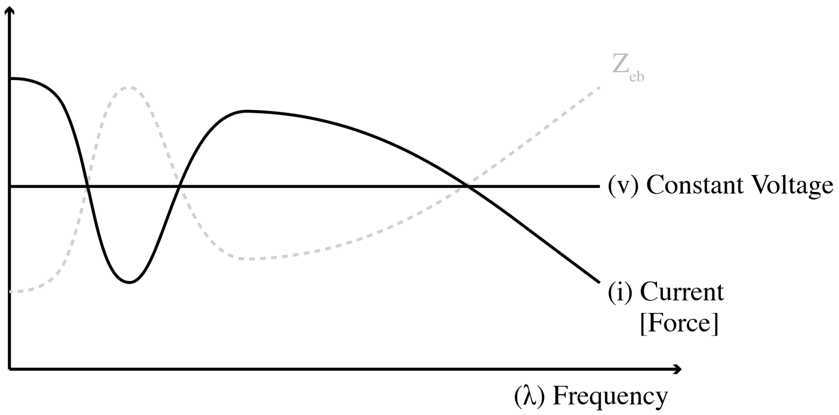
$$F = \frac{BlV}{\widehat{Z_e}}$$

V is the voltage across the driver terminals
Z_e is the total electrical driver impedance, and is given by:

$$Z_e = Z_{eb} + \frac{(Bl)^2}{Z_m}$$

Z_{eb} = Electrical impedance
Z_m = Mechanical impedance

For a voltage-based amplifier-loudspeaker coupling, the sound is dependent on the voltage of the amplifier's output and the mechanical & electrical impedance of the driver.



The inverse effect of driver impedance in matching amplifier voltage with driving force.
Other factors (not shown) also affect the effective gain of the amplifier.

4.2 Transconductance

Transconductance amplifiers have an output current (i) proportional to input voltage. The amplifier function g() adds gain to, and converts the input audio directly to current:

$$i = g(v)$$

The driver velocity can be shown to be (derivation not included):

$$u = \frac{Blg(v)}{Z_{mo} + Z_r}$$

u is the driver velocity
Z_{mo} is the mechanical impedance in an open circuit
Z_r is the radiation impedance

The electrical impedance has disappeared from the equation. The amplifier does the job of converting the input voltage to output current in a controlled domain. We still have to think about motional and radiation impedance, but the overall picture is much simplified compared to the voltage driven system discussed above.

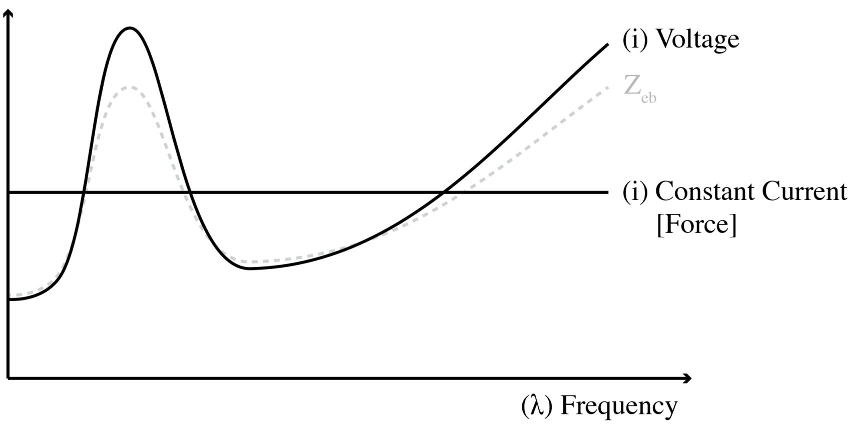


Illustration showing that current control allows the voltage-gain
of the amplifier to match the needs of the driver.

A note on loudspeaker cables: Loudspeaker cables are no longer relevant transconductance audio performance (save for current carrying capacity, where current may be limited). They form part of the electrical impedance of an audio system that has no bearing on the driver motion or sound.

4.3 Controlling Harmonic Distortion

Harmonic distortion is unwanted deviation from a desired motion due to harmonic resonance.

In the voltage world, if an audio signal is amplified perfectly, and the loudspeaker converts the signal to motion in the normal way, harmonic distortion is inevitable as the moving diaphragm will find ways to move, that absorb the input more efficiently. Controlling harmonic distortion is purely the responsibility of the driver in normal thinking. Drivers have become good at controlling harmonic distortion, but they are not perfect, especially when driven with normal broad-band signals.

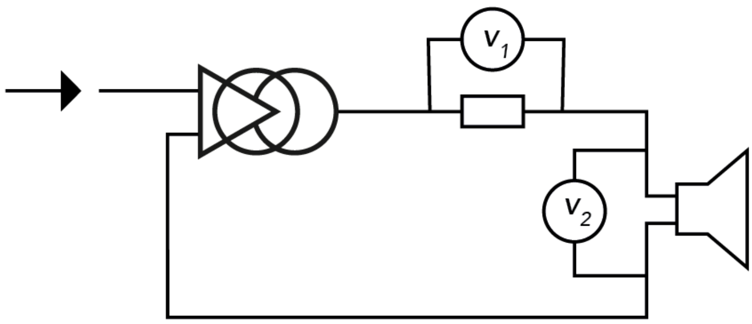
In the transconductance domain, a driver reaches the point where there is a tendency to harmonically distort. Now, an interesting thing happens. The driver's additional movements try to contribute to the current in the circuit that is immediately controlled by the amplifier. The amplifier senses unwanted movement, and actively tries to 'push back'.

As a result, Transconductance is a useful mechanism to actively control some distortions that in the voltage domain are not accessible.

5 TRANSCONDUCTANCE IN PRACTICE

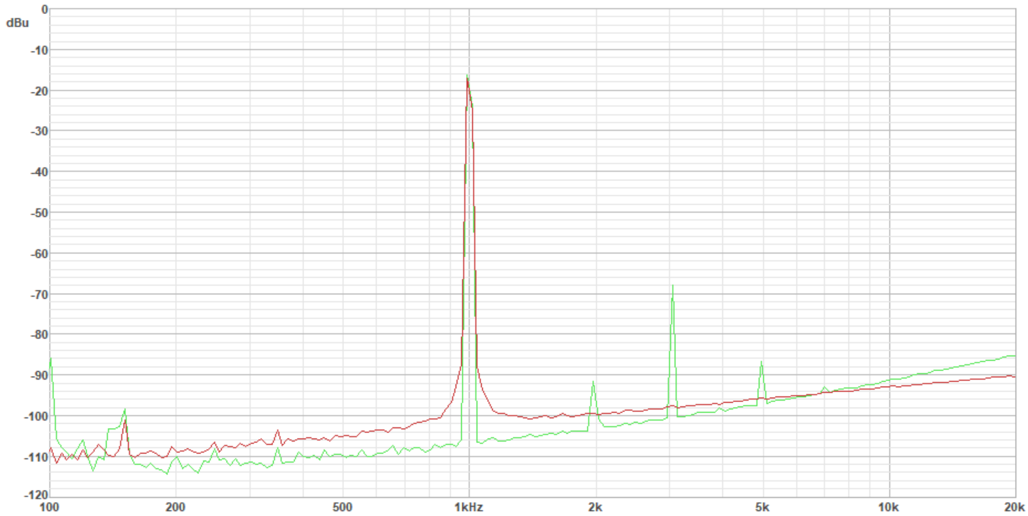
5.1 Experiment: Comparing Voltage and Current in a circuit

The principles discussed so far introduce the Transconductance 'mode of thinking'. The following experiment shows how voltage and current can be viewed differently in a circuit.



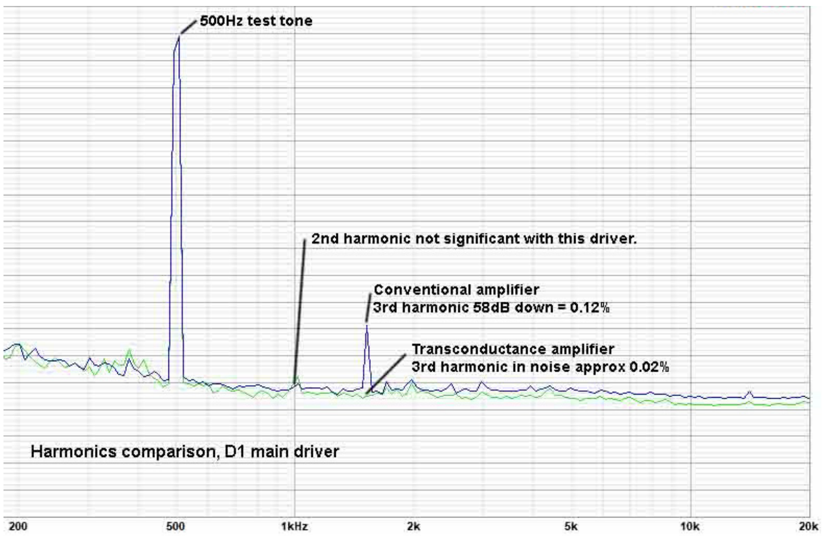
V_1 measures the voltage across a fixed resistance. This is a measurement of current flowing through the driver voice coil as the current in that part of the circuit must be the same as that flowing through the voice coil. (Kirchoff's circuit laws)
V_2 measures the voltage across the loudspeaker.

Playing a 1KHz tone through the above circuit using a transconductance amplifier yields the following result as a frequency spectrum:



The current (red) shows the amplifier doing its job. The tone is clear, and there are no significant currents flowing at any other frequency. The input signal is converted into current.
The voltage plot (green) reveals an increase in voltage in 2nd and 4th harmonics, and a very strong increase at the 3rd harmonic. At these frequencies, the driver voice coil has a higher Z. This illustrates the dynamic and interrelated nature of harmonic resonance and driver impedance. With a voltage amplifier, these Z changes will result in changed acoustic output.

5.2 Experiment: Voltage and Transconductance amplifiers



The above plot shows a spectrum analysis from a driver being driven normally with a 500Hz test tone. The blue line shows the result when driven with a normal voltage mode amplifier. The green line shows the response when driven with the same amplifier, operating in a transconductance implementation (with current sensing feedback).

The driver is a high performance ‘Hi Fi’ midrange driver, and is being driven well within its design parameters, but the reduction in 3rd order harmonic distortion is highly significant.

6 REFERENCES

1. Esa Meriläinen, 'Current Driving Loudspeakers', 1st ed, 2010