

Chapter 5: Understanding Impedance In Audio Transformers

A White Paper from Lundahl Transformers
www.lundahl.se

Presented by ProSoundWeb
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LUNDAHL
- TRANSFORMERS -

Introduction

The term “impedance” is the backbone of all things audio, fundamental to understanding how an AC circuit behaves in respect to its input source and output load. For those new to electrical theory, all audio signals are AC, or alternating current. This includes the power amplifiers that drive loudspeakers, signal level devices coupled to other signal level devices, microphones and direct boxes, and in particular, audio transformers.

Transformers are of special interest because they are capable of transforming impedances, while also providing galvanic isolation, along with many additional benefits.

Impedance & Resistance

In order to understand impedance, it's useful to start by clarifying the difference between impedance and resistance. A measurement of DC (direct current) resistance is a simple function that stays relatively constant, except in the case of the resistance value changing either intentionally – such as rotating a pot shaft – or situationally, such as the heating of a lamp filament or a loudspeaker voice coil. Heat inevitably causes DC resistance to rise in value. As temperature increases, so will the resistance of the wire that the current is passing through.

Impedance, on the other hand, is not as simple. To comprehend impedance we have to understand the relationship between voltage and current in a given circuit. The definition of impedance: “The measure of the opposition that a circuit presents to current when voltage is applied.” Therefore, the magnitude of the impedance is the ratio of the voltage amplitude to the current amplitude. Don't feel too bad if you don't get it immediately. It's tricky. But it is also the explanation why long cable runs can ruin good sound.

Transformers Rule (The Laws Of Physics, That Is...)

As mentioned above, all audio input and output circuits, all loudspeakers, all microphones, and all transformers use impedance as a measurement of electrical value. This is because they are AC devices, not simple DC circuits. But among AC circuits, only transformers (and their first cousins autoformers) possess the unique property to transform a given input impedance value to a given output impedance value, and vice-versa, without needing an active power supply and the potentially complicated, costly, and distortion inducing circuitry that would otherwise be required to do so.

This is more important than it may seem at first glance. Improper impedance in interconnected circuits leads to all manner of troubles. Optimal interconnectivity cannot be achieved when impedance problems are not addressed. And that's precisely where the transformer comes into its own.

The inherent value of a precision transformer in an audio device can be priceless when it comes to achieving ultimate sonic quality – characterized by flat response and freedom from noise, distortion, hum, and buzz – all of which may be due to sub-optimal interconnectivity. This applies equally to solid-state equipment as it does to tube (valve) equipment.

Source & Load

In normal practice, when two audio devices are connected together, one is the “source” and the other is the “load” driven by the source. The source has a given output impedance, and the load has a given input

impedance. Transmission lines and cables exhibit impedance too, but for simplicity's sake we will not delve into them here. They represent only a relatively small factor, except when very long lines are driven by sub-optimal output stages. In such cases, the capacitive and inductive reactance of the cable should indeed be taken into account, because it can cause current limiting in the output stage of the source, a condition that can be solved by employing a high current line-level amplifier driving a precision output transformer. But that is not a commonly encountered situation.

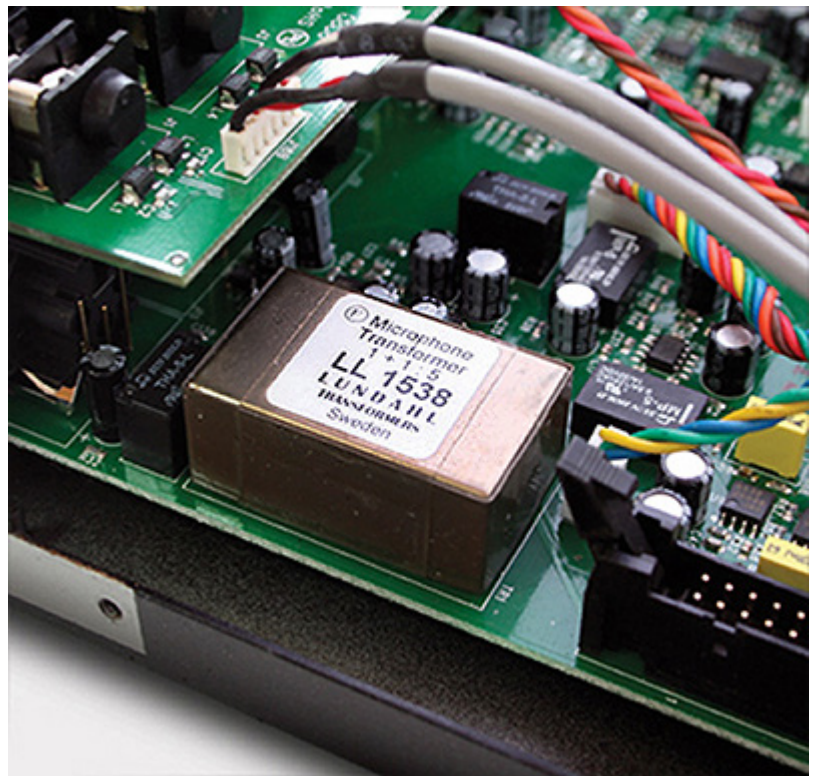


Lundahl transformers inside an Electronaut mic/instrument preamp.

In the early days of audio, product manufacturers attempted to “match” source impedance to load impedance, most often using the value of 600 ohms for signal level devices. This is called “matching impedance” and results in maximum power transfer, an important consideration in long distance communication back in the day when telephony systems were in early development and power was needed to make voice communication audible over long distances.

Now, in these enlightened times, most source impedances of active devices (e.g., mixing console outputs, loudspeaker processors, equalizers, etc.) are kept to a low value, typically around <100 ohms. Most input impedances of signal level devices are much higher, around 10K ohms or more. When the load impedance is 10 times (or greater) than the source impedance, it is referred to as “bridging impedance.” Bridging results in maximum voltage transfer from the source to the load.

At the present time, nearly all audio devices are connected via bridging inputs (low impedance outputs feeding high impedance inputs) because we want maximum voltage transferred between one device and another to reduce the noise floor. Bridging inputs are now so common that the term itself, “bridging,” is hardly ever used anymore (not to be confused with bridged channels in a power amplifier). That said, if you find yourself having to deal with system components in a decades-old sound system installation, it's useful to be aware of the former standard of 600 ohm to 600 ohm matching impedance. Lundahl makes transformers that will enable the proper connections to be made.



A Lundahl transformer at the heart of a Focusrite ISA One mic preamp.

Tubes Are Back

The resurgence of tube-based power amplifiers, microphone pre-amps, direct boxes (DIs), and

even mixing consoles – especially in recording work, but also in many live sound applications – all depend on transformers to match the high impedances of the tubes to useful interstage and output impedances. Guitarists, bassists, Hammond organists and other musicians know, without having to think about it, that the sound they want to achieve is only possible through the use of tube amps and tube preamps. Digital modeling aside (and we're not knocking it), there is nothing quite like the sound and linear control of vacuum tubes in Keith Emerson's organ, or Jimi Hendrix's guitar, to name only a pair of iconic tone masters who relied on tube circuitry and thus on transformers (even if they didn't know it at the time).

But the debate over solid state circuitry versus tubes is not as clear-cut when it comes to mic preamps, DIs, compressor/limiters and other signal processing devices, in which high levels of controlled distortion are not the same goal as they are in instrument amplifiers. That said, a quick glance through a current pro audio catalog will show that tube-based pre-amps, DIs, microphones, and many other products are not only alive and well, but gaining ground. Without the availability of precision transformers – and “precision” is the key word here – the clean, clear, accurate, and sonically pleasing reproduction of tube microphones, tube pre-amps, and tube power amps would not be possible.

The use of tubes in a circuit requires transformers to match impedances from one audio stage to another. And even op-amps and transistors, collectively known as solid state devices, can benefit greatly by the use of transformers. Whether it's an inter-stage connection in a tube amplifier, or multiple solid state devices connected one to another, sub-optimal impedances will “impede” optimal performance. Transformers were developed to address these engineering issues and they do just that.

Does solid state spell the end of the transformer? A good question. Op amps are used in the majority of all modern audio products and the optimal noise performance is attained when the characteristic “noise resistance” of the amplifier, R_n , is equal to the source resistance, R_s . While transformers are not required, as in tube circuits, a precision input transformer will optimize the op-amp to the source impedance, which is unequal to the op-amp's R_n . And that's why many high performance mic preamps that use solid state integrated circuits, also employ transformers.

Microphones

Mics need to provide sufficient voltage to the pre-amp to overcome noise, as well as suitable source impedance and a high value of CMRR (common mode rejection ratio). However, many mic elements are not natively able to do so. This is an important application for transformers which are present in one form or another in the majority of today's mics. Moreover, the last two decades have seen many new tube microphones enter the market. The pre-amp circuits in the mics require transformers to properly feed the preamp stage, which may also be of the tube variety, closing the loop (as it were).

But to fully close it, all-tube mixing consoles also exist, though the breed is rather rarefied. Hybrid consoles, that is, solid state combined with tubes, are more common (though still quite esoteric) in the quest to “warm-up” the sound of digital. All of these products require the use of transformers.

Transformer Function

Transformers consist of coils of wire wound around a metallic core. A signal applied to the primary windings is electro-magnetically coupled to the secondary windings, rather than electrically coupled. That's why we say

transformers provide galvanic isolation. It helps to think of a transformer as a lever. If the fulcrum is in the middle, like in a see-saw, than neither the voltage nor the current will alter from the primary to the secondary.

Figure 1 depicts a 1:1 transformer. The term 1:1 means that an equal number of windings are present in both the primary and the secondary coils. The lever analogy is shown directly below the schematic symbol. This is a common form of transformer, designed mainly for galvanic isolation, though it will also inhibit RF and block DC. (Note: in the figures, U is voltage, I is current, and P is power.)

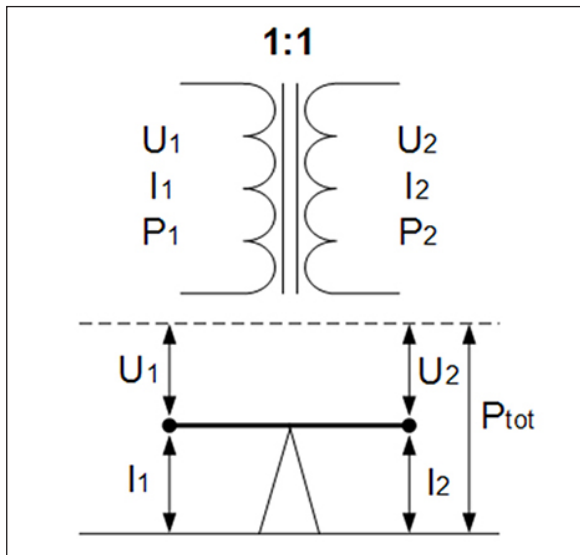


Figure 1

Figure 2 depicts a 1:2 transformer, again showing the lever analogy. In this case, the secondary has twice the number of windings as the primary. Voltage proportionally follows the number of turns and will be two times as high at the output of the secondary windings as it will be at the input to the primary windings (this is a rule of the thumb for an unloaded secondary).

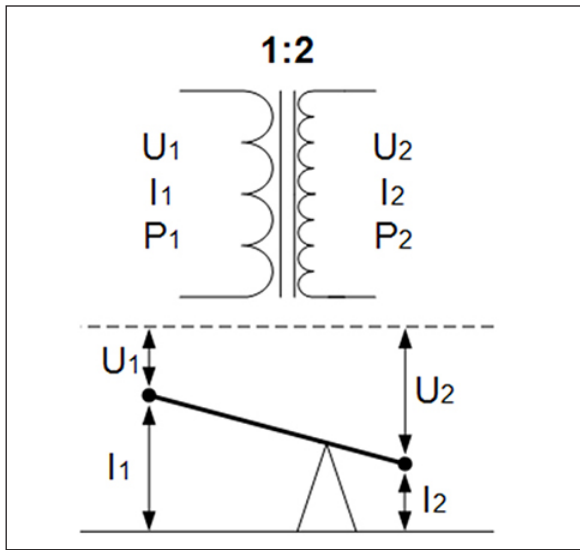


Figure 2

It's important to note that transformers are passive devices and cannot increase power like an amplifier. Instead, they scale voltage and current up or down as needed, to optimize a given circuit.

Winding Methods

In previous papers, we've delved deeply into how Lundahl differs in design and manufacturing, in the quest to make the ultimate transformers for audio applications. But to briefly recap: the majority of transformer manufacturers use bobbins and winding machines that can be purchased for a price.

Lundahl takes an altogether different approach. The company has perfected a unique stick-winding method of constructing audio transformers that sets them apart from virtually all others. This unique winding methodology, combined with top quality materials and exhaustive attention to detail, add up to flat phase and frequency response, exceptional linearity, and extremely low distortion.

These properties give Lundahl transformers an unembellished sonic quality that would be impossible to achieve without the decades of research and development that shaped the company's approach to transformer design and manufacturing.

In the next chapter we'll discuss in greater technical depth how transformers are used to optimize circuits, and will even add in a little math to illustrate the points.

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About The Author

Ken DeLoria is senior technical editor for ProSoundWeb and Live Sound International magazine, and has had a diverse career in pro audio over more than 30 years, including being the founder and owner of Apogee Sound. The author wishes to thank Lundahl senior engineer Mirza Zametica for his considerable contribution to this paper.