The Audio Note™ Transformer Design Philosophy

The Theory

The electronic valve is a high voltage, low current device which is incapable of driving a low impedance loudspeaker directly. Although output-transformer-less (OTL) designs have appeared from time to time, with these types many devices are connected in parallel and a large amount of negative feedback is used to achieve a workable, but not necessary satisfactory result. The efficiency of the output transformer less circuit is also always very, very low due to the severe impedance mismatch, so a large amount of power must be dissipated within the output valves to achieve a tiny output into the loudspeaker. The only way to correctly match a valve output stage to a low impedance loudspeaker is via a step-down output transformer.

The transformer is sometimes seen as a barrier to amplifier performance, and whilst on a theoretical level this is to an extent is true. A transformer does have a finite bandwidth, but as will be shown and discussed later in this article, when properly researched, designed and made the limits achievable in practice are more than wide enough for what is required by the harmonic envelope of a musical signal. Most of the problems normally referred to in this regard relate to problems in amplifiers utilising negative feedback. The limited bandwidth (which may still exceed that of the human ear) and associated phase shifts can make the amplifier unstable, this situation is made considerably worse if there is a strong high frequency resonance present in the transformer itself.

The Design

At Audio Note™ we have spent many hundreds of hours involved in a combination of theoretical research and experimental work to develop and combine proprietary interleaving methods and winding techniques to extend the bandwidth of our transformers to the point at which they could be considered not only excellent components from the technical standpoint, but virtually invisible from a sonic perspective. In some of our designs as many as five wires are wound onto the bobbin at the same time, using these methods a bandwidth of 5Hz to 200kHz is achievable with a transformer for single ended operation of a 300B triode. This extended bandwidth presents the valve with a constant impedance load across the audio range thereby minimising distortion, and allows all of the harmonic overtones and transient events of the music to be accurately reproduced within the harmonic envelope.

Perhaps not surprisingly, we have found that the materials used within the transformer greatly affect the both the sound quality and measured performance. This is an area largely overlooked both now and in the past cost and ease of use was and still is the primary considerations.

Theoretically speaking, the Interleave Insulation and Primary to Secondary Insulation acts as the dielectric in a distributed capacitor, therefore it can be seen that the properties of the dielectric material will affect the electrical and sonic performance of the transformer. Electrical quantities to be considered are dielectric constant, which affects the magnitude of the resultant distributed capacitor and dielectric absorption, which causes distortion by hysteresis. A vacuum is off course the ideal choice as it has a low dielectric constant and no dielectric absorption, but a vacuum is as impractical as it is unrealisable in anything but a laboratory. We have therefore experimented with every man-made plastic insulating material available, but in the end we found that the best sounding material is a special type of paper. Paper is a natural material, and although subject to variations as are all such materials, it is more conducive to creating a natural sound. As with all Audio Note™products the ear was the final arbiter as to which material was to be used.

The Wires

The wire used to wind the transformer is also critical and in this area as in many others Audio Note™ was the company that pioneered the finest, Silver and it was therefore natural to put silver to good use in our best output transformers. Why silver sounds so superior is still not fully understood, but it is unlikely to be simply a function of conductivity.

One theory puts forward the notion that the intense AC electrical and magnetic fields within the transformer interact in some way with the wire material. Another theory considers the crystalline structure of each material copper is very sensitive to impurities, in particular oxygen, it is also possible that the differences are caused by effects that occur on the surface of the material. Surface chemistry is different to that of the bulk material, the atoms at the surface are exposed, rather than being enclosed within the crystal lattice. When the metal is drawn into wire the surface will quickly adsorb components of the air, particularly oxygen and nitrogen as they are most prevalent and despite our best efforts (we coat our immediately it leaves the die), some contamination still takes place. After a while a bulk reaction takes place producing a layer of oxide and sulphide. Silver and copper compounds are similar chemically but not identical. Copper oxide is a rather poor semiconductor compound capable of producing rectification effects whereas silver oxide is a good conductor and is used in switch contacts and batteries. It may be possible to draw wire in an inert atmosphere such as argon and then cover the wire before it reaches the air or to chemically treat the surface before coating to further improve the wires.

The Cores

The core of the transformer is vital for it's operation. In our standard transformers we use good quality silicon steels but in our finest specialist transformers we make no compromises and use the very best and very expensive nickel irons such as Radiometal. 3% silicon steel is widely used around the world and is produced in vast quantities China, America, Japan, Russia and the UK are amongst the countries where this material is manufactured. For our economy transformers we use a material known as M6, in laminations of 0.35mm thickness. The material is first cold rolled, to align the grain structure, into a tape then it is punched into laminations. The problem with this is that the flux runs anti-parallel to the preferred direction at the back of the "E". This means that at that point the materials full potential is not realised at that point increasing losses and decreasing effective permeability. M6 steel has reasonably low hysteresis, good permeability (approximately 10,000) and high saturation flux density (approximately 2T or 20,000 Gauss). The problem of poor grain orientation is alleviated if we move from I-E laminations to a C-Core. Here the metal tape, after being cold rolled, is wound into a loop and then cut, now the magnetic flux always travels in the preferred direction in the steel, this alone gives a significant increase in performance. When we move up to a C-Core we change the material's specifications to M0 or HiB silicon steel a material that has slightly lower losses and higher permeability than M6, the permeability of HiB can be 40,000 or more. HiB is processed in a different way to M6 giving it a different grain structure this special material is manufactured in Japan and America only. Our finest transformers use two versions of Radiometal core in the form of a C-Core. Radiometal is a 36% Nickel iron and Superradiomatel a 48% Nickel iron alloy of excellent magnetic properties the permeability is similar to that of HiB but it's saturation flux density is lower at 1.6T or 16000 Gauss. Radiometal has a much lower hysteresis loss than silicon steel and is far more sensitive to small signals. If one is to firstly listen to a transformer with the best silicon steel core and then change to one with the Radiometal core, one experiences more colour and texture in the performance and more low level details are present. The high frequencies are so much clearer. It is like the difference between an artificial light and sunlight.

A Little History

Traditional transformer designers still use winding calculations and technology that were established in the 1940's, just after WWII, these calculations are designed to yield the best results from a standard M6 type C-core and companies like Partridge, Savage, Parmeko and Gardners made excellent examples of these types of conventional Push Pull output transformers in the 1950's and 1960's, however, the when the new highly permeable magnetic materials such as the Radiometals emerged in the 1950's no-one realised that they require a quite different approach to winding technique to get the best magnetic coupling between the windings and the core possible and thereby utilising the capabilities of these fine magnetic materials fully. Over 40 years later Audio Note™is so far the only company in the world to conduct such work. Work, which is further enhanced by the advantage of having both in-house transformer and circuit design capabilities side by side, something which allows Audio Note™ to design our transformers specifically for a specific circuit thus maximising the harmonic envelope and dynamic transfer and utilising the best combination of both, because we can always check the sonic properties of any given combination during the prototype stages.

No other audio manufacturer have this in-house facility, and there have to source standard designs from transformer manufacturers who do not have the ability or necessary understanding of electronic circuitry to test and design the best possible transformer for each specific application, but will always supply a compromise.

In contrast Audio Note™ designs its best transformers practically without cost restraints a fact which has resulted in a transformer quality undreamed of even 20 years ago, the completely "invisible" transformer is a goal so far unattainable, the Audio Note™ silver wired Super Radiometal 48 C-core transformer is the closest alternative!

The Single-Ended Transformer

One final point of interest with a S.E. transformer is the air gap. This is necessary in order to bring the operating point of the core to the correct region on its B-H curve. It does not seem that anyone has ever experimented with anything other material than paper or plastic for use as a spacer between the core limbs. At Audio Note™ we have discovered that the use of a metallic spacer reduces the distortion produced by the transformer and the improvement in the sound of the transformer is considerable provided the correct material is used and it is applied in the correct way.

Overall a transformer could be described in a similar way to a culinary dish. To get the best flavour one must use the best ingredients and cook them in the correct way and as new ingredients emerge and are developed, be sure that Audio Note™ will be the first cooks to write the new recipes…

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