SE Transformer Design Considerations – By Jack Elliano

SE TRANSFORMER DESIGN CONSIDERATIONS

There is much misinformation about Single Ended Transformers (SE) resulting mostly from the expressed views made by "experts" which come from unfounded theories of this complex device. Due to silver tongued advertising it has become necessary for Electra-Print Audio to call attention to incorrect information in order to speed up the process of ordering a correct and practical transformer.

BANDWIDTH

A single ended transformer cannot have a frequency response from 2 Hz to 80 kHz. A more realistic and practical average bandwidth is -1db 25Hz to 25 kHz. This bandwidth is measured with the tube plate resistance included from the signal source. Measured this way, the transformer will now operate exactly as stated with the tube type indicated.

HOW NOT TO MEASURE A WIDER BANDWIDTH

If you remove the series plate resistance from the signal source and connect the signal generator (600 or 50 ohms) directly to primary the measured bandwidth of the same transformer will be very wide, about -1db10hz to 70 kHz. This is because the low source impedance shunts out most of the inductive reactance and the transformer becomes a capacitor. Now you are measuring the output of the generator through a capacitor. The reason low plate resistance triodes work well here is the same process. These incorrectly applied measurements have simply been published to embellish advertising and price.

CORE MATERIALS

Nickel laminations are used for low level audio, which have little or no winding current. But nickel saturates quickly and distortion will result at the bass end due to the primary inductance which decreases with higher signal level. Nickel cannot be of any practical use in SE type transformers because an extremely large amount of nickel laminations would need to be used with a large gap to slow its saturation. In the end, this would act just like standard lamination material. It's important to note that large nickel laminations are not manufactured and that standard laminations are a fraction of the cost of nickel. Cobalt is similar to nickel plus it is much more expensive than nickel, forget it.
Amorphous cores have there use with higher frequency service. They were originally developed for aircraft equipment operating at 400Hz. These amorphous transformers then weighed less per Volt-Ampere (VA). For full bandwidth audio, amorphous transformers can be difficult to design. This material shows less permeability at low frequencies and peak at 1 kHz. Low frequency power response versus core mass could be compromised. A flat frequency response across the usable audio spectrum would then be a problem. These cores are also very expensive. These materials when used with a SE type transformer offer an output that varies with the change in permeability with signal level and frequency unlike the standard materials.

M19 & M6 LAMINATIONS

Core material made of M19 and M6 has been used for many years. The metal alloy is made of metals to offering uniform increase in inductance as flat as possible for power transfer over a given bandwidth.

These materials were developed to sell product to audio transformer companies for the high fidelity amplifier industry back in the 1950's. Designers had the other materials (except amorphous core) and did not use them for these products. Nickel had its place in low level audio for the recording industry.
These standard materials, when used for SE types, would offer the flattest, most efficient power transfer and overall acceptable measurement. M19 is used for SE types due to no zero crossing as in push-pull types M6 is more costly and its attributes not used in SE service. M6 can be used for push-pull as well as M19.

WHAT ARE THE ATTRIBUTES OF M19 AND M6?

When someone states that the sound created with exotic core materials is far superior to standard lamination materials, you must ask yourself what happened to this reviewer's amplifiers bandwidth and power? This sound is just the new setting of the bass and treble controls. Our reviewer will probably just say its "It sounds better" having no idea what happened. We know that if there was an improvement then it should be measurable.
To date there are many materials available but with only two overall differences in the peak permeability minimum (Gauss/Oersted) with an average of 2000 for M15 to M56 lamination materials and 6800 for M6 (75% Grain). This indicates that realistically only two types are any good for a full bandwidth flat response and these are M19 and M6 laminations.

WIRE

Copper wire is used to wind transformers due to it being one of the lowest Direct Current Resistance (DCR) of all the metals used to create a magnetic field. Copper is also used to receive the flux variations in the secondary windings. If silver wire is used for the primary, it will create the same field due to the same amount of turns is needed as the copper. The only difference is a lower DCR than the equivalent copper primary, a costly decision for no performance increase. Silver wire used for the secondary it will be about 200% more sensitive than copper. If the primary has very low level flux motion from higher harmonic content sounds, silver wire will reproduce it. This is the only increase in performance offered by silver wire when used as a secondary.

WIRE INSULATION

If the customer wishes a different insulation to be used with his transformer, he can build it himself. Electra-Print Audio will determine which wire insulation is appropriate for each transformer design.

SIZE

The size of a SE type transformer will be much larger than the equivalent push-pull transformer. Size is mostly determined by the current through the primary winding. But lower frequency response and power level also have an effect. The transformer size will be determined by these parameters and not by the customer. If the customer needs an exact same size transformer to match the other, it is best to find another from the same manufacturer manufactured in the same year or buy two from us. Then they will match in size.

PRIMARY CURRENT

When a specific primary current is needed, this is what determines the primary winding wire size and core mass. If one wants a 100ma primary but with a 200ma maximum capability then we can only build a 200ma transformer with a core mass for 200ma. SE transformers are specifically built for the tube and its single operating point.

SECONDARIES

In an ideal world, the SE type transformer would be a device that makes 100 turns (the secondary) lay right next to every turn of 3000 turns (primary). In the real world, the most efficient arrangement of primary/secondary that can come close to the ideal is to use single secondary impedance interleaved with the primary. For example: a] 4 ohms or 6 ohms only rather than 4 plus 8 ohms or b] 12 ohms for 8 and 16. Also odd impedances like 5 ohms only or any other singular impedance, 5 or 8 or 10 ohms are equally efficient. The reason this is that multiple taps leave unused wire within the winding. These will cause dips or peaks across the bandwidth. Note that the early four secondary arrangements as the ST3KB style are this type with no unused windings.

DETERMINING THE PROPER PLATE LOAD

The plate load for a 300B is 3000 ohms. Not necessarily. Our Western Electric reference book indicates the 300B will operate from 1500 to 6500 ohms load depending on the operation point and job needed. This goes for all tubes triode, tetrode or pentode. When the SE output primary impedance is lower than what the tube is setup for, it will distort. If the primary impedance is higher than what the tube is setup for, it will work well (at least 1% Total Harmonic Distortion (THD) with only a small drop in power. Best operation design for any power triode is to operate it very close to full plate dissipation for highest power output with 1% THD (mid-power) or less.

To find the plate load that a tube likes, use a SE transformer that you know the ratio of. For example, 3000 ohms to 8 ohms use the math 3000/8=375 square root yielding 19.36 or turns ratio. This is the test procedure: a] set up a breadboard with the tube selected, b] set up power supplies and such for full operation of this tube, d] connect a 1 kHz drive signal or viewing signal with a variable secondary load, e] then measure power output take AC Root Mean Squared (RMS) voltage, at the secondary with its load, and finally f] take voltage squared divided by load impedance used. This will give you output power of this tube at its operating point you selected. To see what plate load the tube likes at this operating point for example, highest power at good waveform is, lets say, 10 ohms. Knowing the transformer is 19.36 Turns Ratio (TR) and it is a higher primary load because its now 10 instead of 8 ohms, lets say 4000 ohms to 10 ohm, this gives 20.0 TR, not there yet. Take 3800 and 10 ohms, its 19.49 TR, close enough to 19.36. So plate load this tube likes is 3800 ohms to an 8 ohm speaker.

Testing Transformers – By Jack Elliano

TESTING TRANSFORMERS WITH SQUARE WAVES

PROPER TESTING OF AUDIO DEVICES USING REACTIVE COMPONENTS

Ringing from square wave measurements has grown into a very negative response within the incorrectly informed audiophile group. The influential ones spreading this have probably measured an amplifier that has a flat frequency response from 100hz to 6000hz. This would show no ringing at all.
In order to slow down and hopefully stop a continuous barrage of incorrect technical statements used for influence and profit, it becomes necessary to confront them with facts. An example is: the measurement of speaker interconnects of its inherent capacity and inductance involved as featured in advertising. Realistically there is a problem with music that is played in the megahertz range. One statement heard to confront this is, "These advertised measurements are like being concerned about the aerodynamics of a golf cart." This is the intent of this article. TRANSFORMERS THAT RING WHEN SQUARE WAVES ARE APPLIED
A square wave is composed of a leading edge with a rise time in the megahertz range (depending on quality of generator and frequency used) then to a given duration of a DC voltage across the top, then switched down (same speed as the rise time) in the megahertz range then to cross zero and repeat in the opposite polarity. Just to inject something here, we did have a transformer that will pass a DC voltage, it was shorted out.
This bipolar waveform, when measured with a Fourier series analysis, shows the square wave is composed of its fundamental frequency and an infinite number of odd harmonic frequencies. The even order content would have to be zero for a perfect square wave.
The use of a square wave to analyze an amplifier is shown in full in Tremaine's Audio Cyclopedia, 2nd edition, Audio frequency measurements chapter, pg. 1521, as a means to test the transient response of an amplifier. If the amplifier has ringing at the top of the leading and falling edge, this shows an extremely good high frequency response from the transformer in use. Well, there it is folks!!
If one remembers the ignition system on the old engines, they used a set of points, generating a square wave of 12volts and applying this to a capacitor and spark coil (a very high ratio transformer for those who don't know). They rang to 15,000 volts or so. This is what a square wave will do to this combination of coils and capacitors.

AUDIO TRANSFORMER RINGING

A basic audio transformer with, lets say, a 10k primary and a 600 ohm secondary. We do know that the primary has many more turns than the secondary. Lets say that the total length of the primary wire is 1000 feet long and the secondary is 100 feet long. For this transformer to be perfectly coupled (little or no ringing), it would need to have the 100 foot secondary wire fully coupled next to the total of all the 1000 foot primary. How can this be done?? Well it can't! End of statement. If one is to build a transformer with different primary to secondary ratios, like most of them are, then some portion of the primary is not coupled to the secondary, therefore ringing will occur due to what is called "leakage reactance". This is the measured primary inductance left on the primary when the secondary/s is shorted.

This reactance will react with the capacity within the coil to resonate. when a square wave is used and it is composed of the frequency (usually in or near the megahertz range, ringing can occur.
When a transformer is in operation and loaded, the open winding or static inductance measurement is lower.
Much higher though than the shorted "leakage reactance" indicated above.
The ability to ring with a square wave is in play usually within a 10khz square wave.
An example is a class C operated RF amplifier, the output power, which is a pulse, going to the tuned tank circuit (coil and capacitor), tuned to resonance, will show a ringing waveform. The flywheel effect of the high Q resonant tank circuit, stores, combines and transfers this energy to the antenna as one frequency. By the way, this tank circuit is a transformer with a primary about 20,000+ ohms to a 50 ohm secondary, with no core. That's another story.
The one audio transformer that will show little or no ringing is the bifilar wound (two equal lengths of wire wound together equally in turns); this is a 1:1 ratio type with total coupling of all wire involved. Try to design and build an amplifier with only 1:1 transformers. Smaller variations of this bifilar wound transformer are known as pulse transformers, usually used in radar and other pulse operated circuits. A pulse is a square wave of one polarity. Get the picture.
To sum it all up, a transformer is probably the most complicated device ever invented. Its many intricate designs and uses, then to have the few accepted, and common measurements made by those who never even built a transformer, evaluate them for all, is simply absurd.
Have you ever seen a wideband oscilloscope preamp circuit use a transformer? Those of you that have circuit experience will answer NO!!
To cap it off, those influential few who apply square waves to test and evaluate transformers could probably say "we played the clarinet by blowing into it backwards and it sounds very bad so in our opinion don't buy one."