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Unwinding Distribution Transformers

by Paul Mathews

Paul Matthews of Rane Corporation has authored an excellent paper on the inner workings of the distribution transformers used in high voltage systems. These components are often taken for granted, but differences in the performance of various models and designs is significant. The entire work is fifteen pages, so I present the intro along with a link to the full PDF. pb

What could be more mundane than the transformers and autoformers that are the backbone of most audio distribution systems? This article will show you that there is a lot more going on with these chunks of iron and copper than you ever suspected. You will also learn why transformers are often the power bottleneck in distribution systems. Along the way, you will learn how to interpret datasheets, believe or disbelieve manufacturers' claims, how to specify HV components, and how to setup HV systems to deliver the best possible power, fidelity, and bandwidth.

High Voltage Audio Distribution Systems

Although the term Constant Voltage is still in common use, this article adopts the less confusing High Voltage (HV) terminology recommended in earlier articles (reference SAC 2004 article). Most Syn-Aud-Con readers already understand that HV systems are in widespread use for these principal reasons:

- HV systems minimize power losses in low-cost wiring resulting from voltage drops across wire resistance
- HV systems facilitate connection of multiple loudspeakers without careful consideration of impedance matching
- Once an individual power tap on a loudspeaker has been selected, the loudspeaker continually receives the same input voltage even when other loudspeakers are added or removed from the system, resulting in more constant and uniform coverage.
- Volume control by transformer tap at the loudspeaker end is more efficient than resistive pads.

In this article, we first consider what sort of output transformer is needed to deliver the required voltage, fidelity, and bandwidth to an HV distribution system. Then, we look at how the HV loudspeaker loads, each with its own transformer, tap off a portion of the available power on the HV lines. Finally, we re-examine the loading presented to the power amplifier by the combination of transformers and loudspeakers, and conclude that load impedance should not be ignored in HV systems.

Transformers at the Power Amp End

Here is a procedure for selecting an output transformer for an HV system where the required RMS voltage has been determined using suitable methods:

1. Choose a suitable power amplifier and operating output impedance Z_{out}, providing a power margin of 20% to 50% for system losses. Calculate amplifier maximum RMS output voltage E_{out} using Joule's Law (see below).
2. Calculate desired voltage boost ratio, aka turns ratio, $N = E_{HV} / E_{out}$, e.g., N = 70.7 / 28.3 = 2.5. Select candidate transformers with turns ratio within 20% of calculated N.
3. Decide on the lowest system frequency f_{lc} for good fidelity and power delivery.
4. Find datasheet ratings or conduct tests to determine voltage tolerance of candidate transformers at f_{lc}. Saturation voltage should exceed maximum amplifier output voltage expected at f_{lc}. In general, performance will then be satisfactory at all higher frequencies.

Lamination Lamentations: Distribution Transformer Core Saturation

Figure 2 shows primary voltage and current for a distribution transformer driven at a low frequency and

$$W = \frac{E^2}{R}$$

$$E = \sqrt{WR}$$

$$R = \frac{E^2}{W}$$

$$E_{sec} = \left(\frac{N_{sec}}{N_{pri}}\right) E_{pri}$$

where
E is RMS voltage
W is power in watts
R is resistance in ohms
N is number of turns

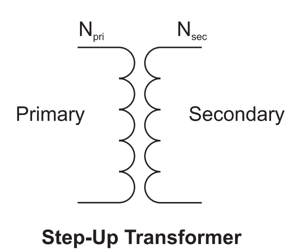

Figure 1 - Joule's Law

with a loaded secondary. The voltage (yellow trace) is a good sine wave, but the current (blue trace) has the sudden spikes associated with core saturation. In order to deliver a low-distortion voltage waveform to the transformer, the power amplifier must be able to supply these current spikes. If the power amp succeeds in delivering the extra current, the voltage delivered to the loudspeaker load will still be a good sine wave, stepped up to HV system levels. The loudspeaker (secondary) current will also a be good sine wave. Of course, this can pose quite a problem for the power amplifier. Core saturation happens after reaching a particular volt-seconds limit on the primary, regardless of how much power flows to the secondary. When it becomes excessive, as in the case above, system efficiency and audio fidelity suffer greatly. Some power amplifiers protect themselves by Safe Operating Area limiting or otherwise reducing their output. The effect of SOA limiting on audio quality varies greatly among power amplifiers. If the amplifier protects from overcurrent spikes by reducing its output drive, thereby raising its output impedance, the resulting voltage spikes can still damage output transistors. If the amplifier protects itself by reducing its output voltage amplitude while maintaining a low impedance, damage is less likely.Because of core saturation, the voltage handling capability of a transformer declines as the reciprocal of the frequency. This means that power handling capability declines with the inverse square of the frequency.

Swingtime: Preventing Core Saturation

Since core saturation happens when a magnetic field gets too dense, improvements in transformer low frequency performance come from design changes that reduce flux density or raise the threshold for saturation. Flux density can be reduced by increasing the core size or by increasing the number of winding turns. Both of these measures increase the size and cost of the transformer. Saturation levels can be increased, to some extent, by incorporating exotic core materials, which also raises cost. Increasing the winding turns is often the best way to improve low frequency performance, provided that doing so does not unduly impact high frequency performance, size, or cost.

Our investigations indicate that many distribution transformers are unable to deliver anything near their rated power at low frequencies. This is a problem if you try to deliver significant power below 100 Hz. In other words, if you want a ‘bottom end’, choose your transformers carefully. Otherwise, you probably need to at least filter out the low frequency content of your audio to prevent saturation problems.

Magnetic flux density can also be reduced by introducing air gaps in the core geometry, and this has the effect of softening the transition from linearity to saturation. E-core transformers have some incidental small air gaps in their cores that produce somewhat different behavior compared to toroids as shown in this scope display (Figure 3) (see also Core Shape: Toroids and E-cores section). Compare the blue current waveform to those in the previous scope display, and observe how the E-core saturation current transitions are less abrupt. In practice, this means that saturation distortion extends over a broader range of frequencies for the E-core. However, above a given power level, distortion at a single frequency may be higher for a toroid transformer. *pm*

The article in its entirety can be downloaded from
http://www.synaudcon.com/nl054/udt_pm.pdf

Figure 2 - Voltage waveform (top) and current waveform (bottom) showing effects of core saturation.

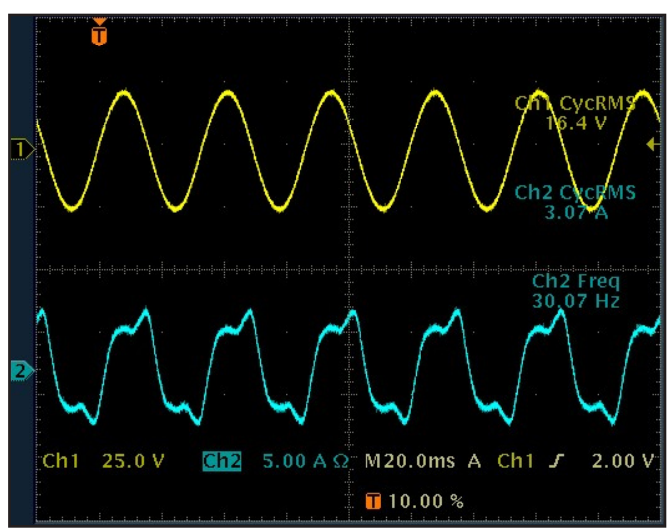

Figure 3 - E-core transformers show an improvement due to air gaps in core geometry.