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White Paper: A New Zobel Network for Audio

26th November 2009

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A New Zobel Network for Audio

A new class of Zobel network[1] has recently been developed for assisting in RF & EMI suppression and spike risetime reduction, and overall offers consequent noise-floor reduction in the audio circuits associated with the device. A commercial realisation dedicated to mainly dealing with amplifier-to-speaker connections is named *Zapperator.* A complementary device incorporated into cables[2], and so particularly suited to line- and vinyl/cartridge-level connections, is *Mini-Zapperator*. This cable-integral version is particularly effective above SHF (above 800MHz). Availability is restricted to world-class woven Kimber cables, as available from Russ Andrews Accessories Ltd.

It may be interesting to learn that Otto Zobel[1] did not specify the name for the network generically known as 'Zobel', and the title 'Zobel' or 'Zobel network' is largely limited to audio power electronics, and immediately related fields. Elsewhere, the same arrangement may be merely titled 'RC' network, or 'RC damper' or 'damping network'; or in more industrial cases 'snubber'. At the same time it fits naturally at the base of an entire family of dissipative filtrative networks he did invent, that also bear his name. But these are now largely forgotten - he is far more famous because of the beneficial applications for Zobels in well-engineered audio circuitry, particularly where there are solid-state circuits and/or loudspeakers. However, it is useful to realise that a Zapperator should not be confused with a loudspeaker Zobel network[3]; nor the Zobel that is *de rigeur* to stabilise most solid state amplifier outputs[7].

Audio care

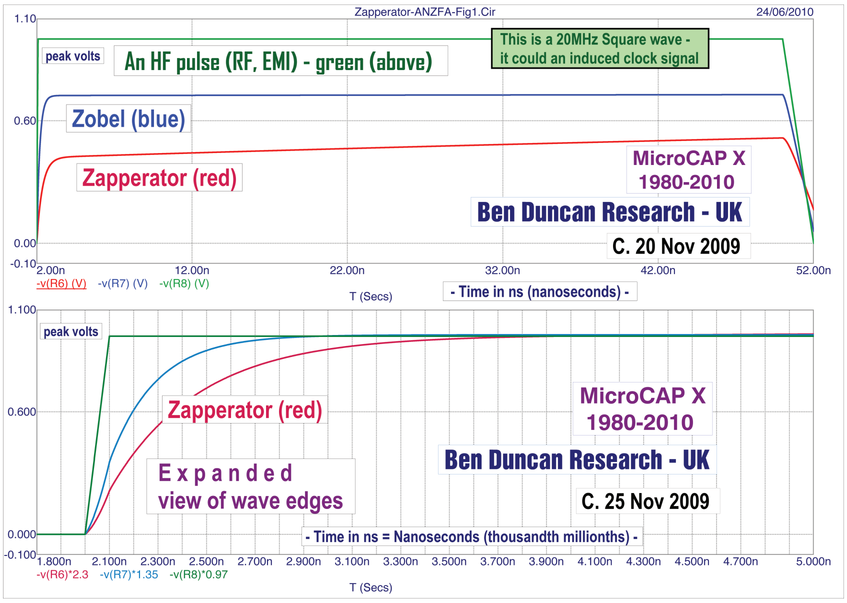
Any form of Zobel-type network connected across an audio line must be subtle. For any high resolution music reproduction system, brute force component value scaling which remotely 'clamps down' on hf extension, or musical dynamics, is ill-advised. Brute force attenuation of RF would amount to applying higher capacitance, lower resistance, or worse, both at once. See the later section 'Some Audio quality considerations'.

When compared to a standard 'Zobel' network[4], the new class of Zobel network offers its improved performance with no increase in the overall capacitance and resistance employed across the line. Therein lies just one reason for its enhanced performance.

Operational Benefits

Analysis, employing Spectrum Software's# MicroCAP 9 simulation software, compares a standard Zobel with the new Zapperator type of network. With transient events, looking in the time domain, **Figure 1** shows that the new type of Zobel has a far greater 'shock absorbing effect' on fast[5]- changing wave fronts. This includes efficiently reducing the height of 'fast'[5] spikes.

Fig.1:

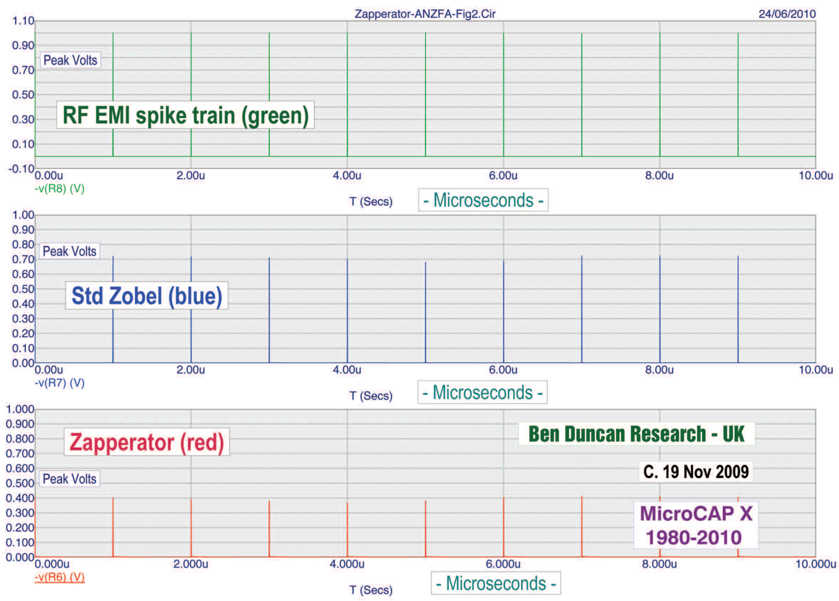


Plots were updated to the latest MicroCAP X just before public release, in June 2010.

As identified by Russ Andrews over 15 years ago, such a plethora or train of 'fast' spikes (on or induced from, the AC supply) may be invisible to all but the most specialised measurement setups, yet able to create audio-band noise in audio equipment. This is naturally most (but not exclusively) evident in higher quality equipment having low self-noise. The noise created by RF and RF EMI such as fast spike trains, may be perceived only subliminally, yet is capable of smothering musical detail, or of adding a disturbing quality or edge. This in part is because spikes can also result in slew-limiting - that then affects biasing and so alters or raises audio distortion, both the latter for periods extended vastly past a single spike's own duration (see below).

Removing RF noise impulses, or preventing their worst effects, is one of the 'duty areas' that Zobel networks excel at. In this context or guise, they may be said to be snubbing. The keynote is extra loading and dissipation of edges and impulsive energy. The RF is 'burnt away' - got rid of as heat. This is part of the 'zap' concept: the RF can't spring back. The relevance is that with filters, which mainly depend on L-C networks, it can return. Or, cause problems elsewhere. As the usual kinds of filter (made for brute power efficiency without any other perspective) have often only really 'batted the unwanted energy away', with the blithe assumption - or open-ended hope - that the energy will 'go hang' elsewhere. But with the Zobel, the energy gets transformed into heat. **Figure 2** below shows the Zapperator's 'spike eating' reduces a 1ns spike-train's amplitude by

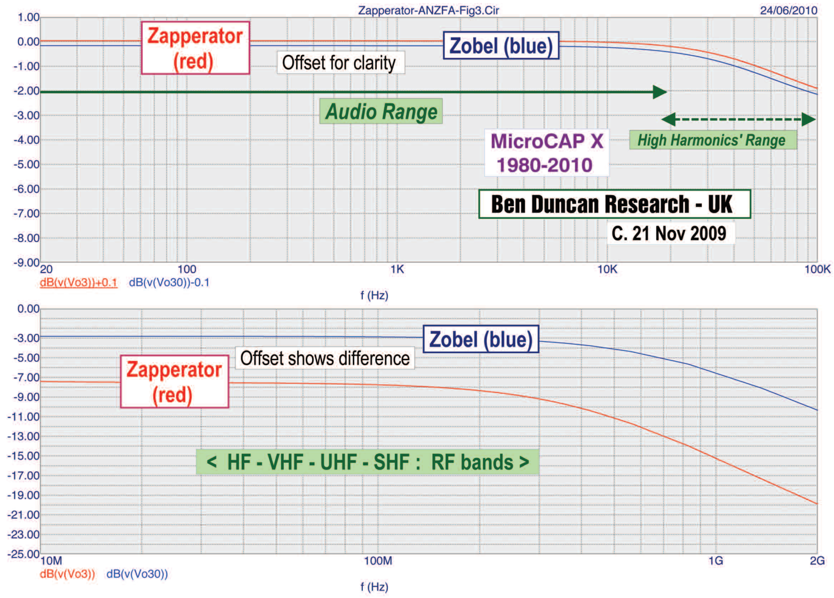
Fig.2:



around 6.5dB (just below a halving), while the regular Zobel used for comparison manages a worthy 3dB or so. It is very important to realise that these are relative figures, and very probably quite worst case absolute results, with the RF/EMI source impedance being set at 75 ohms. In other words, with more typical RF/EMI noise source's source impedances, the attenuation might be say 9 and 12.5dB; or 20dB and 16.5dB. In each case, the Zapperator's extra 3.5dB reduction remains valuable, particularly considering threshold effect. This is the threshold level, above which AM content in RF, is detected, which may worsen the ill-effect, in one tiny step. Equally, the ill-effect of RF may vanish or fall greatly, with one small step the other way. As to the seemingly small achievement of 3.5dB, anyone who has engineered with multiple constraints knows that such improvements may be hard won.

Analysis in the AC domain, again using MicroCAP-9, indicates the Zapperator's extra efficiency in the high UHF and low microwave realms - **Figure 3.** Network analysis performed with HP 4396A and HP 8754 up to and above 1GHz, confirms useful suppression is achieved (in 'realspace' - actual production realisations), albeit less perfectly smooth in the leaded form. Not surprisingly, having the tails lightly twisted together helps. The attenuation at high RF, above 300MHz, then matches more closely what Figure 3 predicts.

Fig.3:



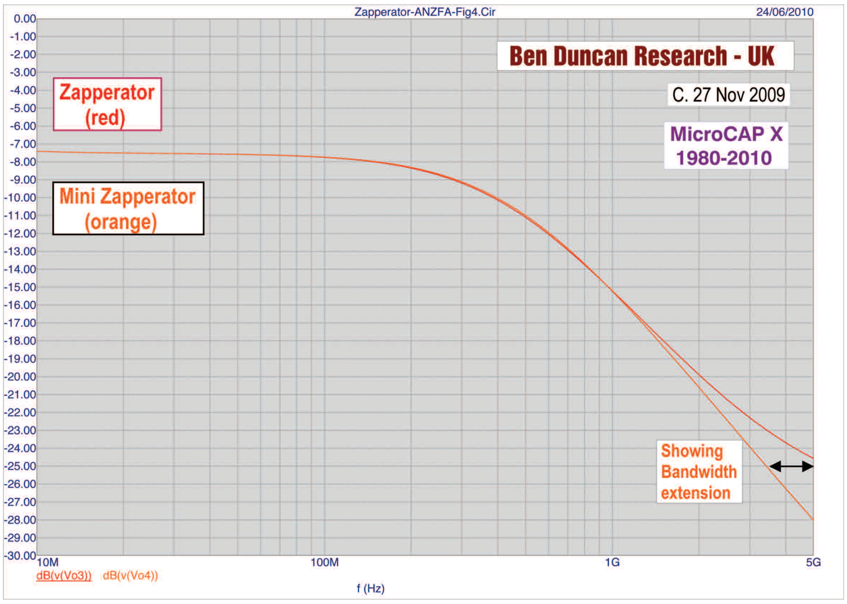
Note 1- To protect intellectual property, and patents pending, an area of response is subject to non-disclosure. As the unit's greatest value is at higher frequencies, the undisclosed area hardly diminishes the displayed benefits.

Note 2 - It is assumed the reader realises that all simulations are ideal, and that physical realisations will display ripples and variances.

The Mini-Zapperator comes into its own above 800MHz, including the 2 to 4GHz area of wireless 'consumer' equipment. It is essentially 'non-leaded', which means much less inductance in the connections, which otherwise diminishes and ultimately 'messes-up' the Zapperator or indeed, a Zobel's operation at high RF; or at least reduces its scope. This extension deeper into microwave territory of the new Zapperator-class component is achieved by the parts being 'built across' the conductor (cable) ends, as part of a 'Y node'. Meaning the port, the cable end and the Zapperator terminations are all joined as and at a star point. This is a specialised and delicate procedure, since few audio cables of any sort are ideally structured for microwave engineering, nor are the usual connectors. If they are, they are often then unsuited to high-end audio.

Figure 4 shows the predicted response extension, of the Mini Zapperator's attenuation - all above 1GHz. 'Realspace' plots are less neat and measurements are less easy to make, and may even be less definitive, but those made are essentially confirmatory. [8]

Fig.4:



Overall, the Zapperator, with its high-flex leads, can be connected to any cable or system, at any level, while the mini-Zapperator is solely integrated into suitable cables. The optimum cables chosen were Kimber, because the woven structure has some special EM (electro-magnetic) properties that are apt to work synergistically with the Zapperator class of networks.

Slew Limit - An awakening after 30+ years

To understand another dimension of the benefits of Zapperator technology, in today's world, consider slew limits for audio - that a circuit capable of (say) 1.25v/µS (one and a quarter volts per microsecond) can barely handle 20kHz at 10v peak, as this is at the onset of plainly visible, hence serious, 'wave bending', and so distortion becoming extreme.

Next, consider that the relationship is linear. So for signals at 1GHz*, we can see that slew-limiting will likewise onset visibly and grossly, with a peak signal value that is 50,000 times *smaller* than whatever voltage is safe at 20kHz. So 10v becomes 200µV. For a lower acceptable degree of non-linearity (this means sonic degradation), we might reasonably set a slew rate limit, the maximum rate in the signal applied, of a 1/10th or a 1/100th of this, as being 'safer'. For a start, the harmonic structures arising at different percentages of and below the limit, are unknown and unexplored. So conservative measures are valuable to be sure there is no distortion, hence no intermodulation, hence no extra noise generation, hence a lower noise floor. Then in using the 1/10th criterion, the 1GHz limit would be 20µV. And with the 1/100th, the maximum peak value for signals around 1GHz is 2µV (two micro-volts). This signal level is typical of weak RF broadcast signals. Considering most audio cables are not hermetically shielded at RF, nor are able to be, RF voltages at these levels - or higher - are 'not unlikely' to be found induced into the associated conductors, in most places today. Accordingly, it is valuable to have other means to reduce not just RF amplitudes, but equally - or even more preferably - to reduce the high rates of change, of RF signals that have frequencies up to thousands of times higher than the highest audio-relevant harmonic (which means dealing with them needn't affect sonic quality).

The results of RF causing slew limiting are surprisingly long established, although the cause is infrequently identified. Critical operational DC levels inside circuits may be altered, including amplifier biasing, and in turn, the stability and poise of electrolytic capacitor dielectrics can be upset. Sharp edged pulses can also give rise to trauma to some materials inside equipment optimised for audio, notably the plastic dielectrics of cables, capacitors and semiconductors. Of course, direct effects may well prove invisible. The structure and audio quality of 'impulsed' materials may take several days to return to normal. Such might explain the sometimes noted sudden loss of sonic quality - possibly after a flare-up of RF spikes arising from sun-spot activity or lots of thunderstorms, for example. Such vast noise sources may induce spikes directly into the audio path, via speaker voice coils, crossover parts, speaker wiring, or amplifier wiring, inductors - let alone via line-level connections, and the surrounding AC power wiring.

* 1 GHz(One Giga Hertz) is a frequency 50,000 - fifty thousand - times higher than 20kHz (Twenty kilo Hertz).

Multiple, inter-related Benefits

In summary, *suitably-dimensioned* Zobel networks, and Zapperator-class networks all the more, are able to act to protect sound quality and high-end equipment, in several ways:

i) Reducing the rates of fast signals, spikes and impulses. These are rates many thousands of times above those of the highest audio signal frequencies so that ample reductions won't affect audio quality *one iota*.

ii) Attenuating RF levels above useful audio frequencies, with a resistive termination impedance progressively developing at higher RF, where this is most valuable. Providing a stable RF termination to continuous or steady waves, close to a suitable value, for many real world conditions, where characteristic impedances are, in practice, complicated, multiple and partial.

iii) Operating as an attenuator of fast hard-edged impulses, from low-mid RF (far above audio), to SHF (microwave frequencies) with the Mini Zapperator extending well into microwave realms, the area where most mobile phones (except US), many satellite up/down links, and also wireless -audio and -LAN, all radiate.

iv) Operating as a fast spike absorber, and oscillatory event damper. With no risk of returned unwanted energies - unlike with filters - that employ inductors.

v) Providing a stable RF termination to continuous or steady waves, close to a suitable value, for many real world conditions, again where characteristic impedances are in practice, complicated, multiple and/or partial.

vi) Ease of application. Life is complicated enough. Zapperators are 'free-form' devices. Meaning their location - which end of the cable, and direction or polarity ('which way round') is unfussy. They may be openly experimented with. There are very few things to be wary of. In some instances, a Zapperator may be preferred, results-wise, when sited at the power amplifier 'end', or at the speaker 'end'. Or at both. Possible causes are myriad, and experiments are far quicker to conduct, and often more effective, than analysis! (experiments yield results; analysis yields paper. Paper is not a result.)

Some Audio Quality considerations

A single Zapperator costs above £50. A snubber suitable for industrial arc suppression can cost the same, or many times more, or just £5 (all figures are for illustration only). Although both can be simplistically represented as similar electrical assemblies, there are a number of vital differences.

An industrial snubber part is just a zobel, and never a Zapperator. High grade industrial snubbers (costing over £100) are designed for not catching fire with very high currents, and repetitive use. Audio requirements aren't on the list. Quite apart from whether it has the right values and dimensions - there's little choice or subtlety with industrial snubbing components. The same applies to low cost snubbers. Quite apart from the harmonic distortion that the dielectric construction (if polyester alias PETP alias Mylar) will add, such a snubber (where of low cost) will come with solid copper leads only if you are lucky. More likely, they will be solid steel leads, with a thin coat of copper 'sprayed on'. After a few bendings, the metal is fatigued, and eventually breaks. The item becomes unusable scrap. But before it does so, it may do more harm than good. For, when copper (or steel) wires are flexed a lot, the metal work-hardens, hence the metal becomes more crystalline, hence more diodic, hence the component may create noise, by detecting AM content in the incident RF energy. Note! Even FM signals and digital signals can have AM content. In this way, a wire connection with fatigue (which can be quite hidden) may add or cause more 'noise', than it suppresses.

Not only are the internals quite different from an industrial snubber, Zapperators benefit from a highly flexible audiograde wire having measurably low directionality[6], as well as low fatigue. Thus the tails (the flexible connecting wires) won't degrade audio quality in time - as an embrittled steel or even ordinary stranded copper wire would. Or break, even after hundreds of flexings. In turn, sonic experiments can be carried out by users, without worries as to the Zapperator wires gathering fatigue. Such might otherwise deter a user from discovering the sonic benefits of the optimum placement/s.

The very flexible leads fitted to the Zapperator are also designed to damp vibration from speaker cabinets and equipment mains transformers. Holistic design extends to the encapsulation which absorbs incident RF energy and also acoustically damps and deadens the internal components.

Some further High-End Audio demands

The Zapperator and Mini Zapperator are RF attenuators and terminators, both static and dynamic. It sounds simple, but the designer faces the challenge of melding niche (specially discovered), good sounding parts (finding those is a job in itself), that won't upset audio quality, with components that will also be effective at radio frequencies, over multiple decades of frequency.

The components used also have to withstand the commonly high levels of bass vibration next to a speaker cabinet, usually many times higher than that at the listening position, again without audio-quality degrading effects taking place. For example, many fine RF parts may be microphonic, and not with linearity. Use is then akin to connecting a distortion injector into the audio path. This is a common problem with audio accessories.

Meanwhile, Electrical or Electronic Engineers who may be knowledgeable at RF have scant appreciation of effects in systems where the signal range needing to be free of error must be nearer 120dB than the 30 to 50dB needed or handled by and accepted for, most RF communications. Broadly speaking, this means that the high-end audio application could be said to make the component quality be at least ten thousand times more critical.

Accordingly, while a termination unit is a simple device in principle, a great deal of knowledge of audio, of real world electronic components, and of manufacturing techniques, is required - particularly to meet what's also required in today's RF field. Design and manufacture are far less trivial than they seem.

This is perhaps shown by the fact that audiograde RF terminations have not been hitherto made available, outside of possibly being necessary, integral parts of some high-end cables.

Application Summary

The Zapperator is the world's first flexibly deployable, audiograde RF terminator/absorber. It may be plugged-in at the speaker 'end' or across the amplifier 'end'. Or both. The optimum is only determinable by the individual user's environment, equipment, hearing, etc. But it is also easy enough to 'plug and listen'. One important point that should be clear: if you don't have an RF problem (at the time of testing), or your equipment isn't sensitive to RF (this can be a feature of simple valve/tube electronics), you might not hear any effect. But, as RF and the problems it can cause, can come and go, seemingly randomly to the listener, and as components other than transistors can detect RF, you'd need to check it daily for some months, to be sure the Zapperators weren't helping at some point.

The Mini Zapperator takes the benefits into higher, microwave realms, for more sensitive line and vinyl-level interconnects, in association with Russ Andrews Accessories and Kimber woven cable technology.

Notations

1. After a class of passive networks by Dr.O.J. Zobel (Otto Julius Zobel, Oct 20, 1887 - Jan 1970) working at Bell Labs, NY, USA, in 1920s, eg. *O. J. Zobel, Theory and Design of Uniform and Composite Electric Wave Filters, Bell Tel. Sys. Tech. J., vol. 2, pp. 1-46, Jan 1923*.

2. presently in Kimber woven cables.

3. Walt Jung (ed.), Analog Devices Systems Application Guide, 1993, ch.8, p.108.

4. An R+C network having values scaled to perform damping, dissipatory and impulse-control duties.

5. 'Fast' is a relative term in electronics; here it means with a duration of under 1 microsecond, and in this and other instances, below 1 nanosecond (the period of one cycle at 1000 Megacycles per second, or 1GHz.). This distinction is made, as spike or transient generally infers not just a brief event, but also one with a steeply rising wavefront, where both 'brief' and 'steep' are again, unless defined, relative terms.

6. Directionality measurements, using the proprietary scheme devised by Ben Duncan, were performed during the development of a test apparatus for Kimber Kable Inc (akin to what was presented in Hi-Fi News & Record Review, Sept 2000, in BD's investigative 'Black Box' column, reprinted compilation available).

7. Ben Duncan, High Performance Audio Power Amplifiers, Newnes/Elsevier, 1996, hardback ref. book, ch.5, section 5.6.2.

8. Martin Colloms, Cables and RF interference, HIFI CRITIC (journal), Jan & Feb 2010. This article includes original and authoritative measurements of RF in speaker cables, including with and without a Zapperator, viz. Figures 18a and 18b, that broadly dovetail with the simulation predictions.

Zapperator & Mini Zapperator

Concept & Audio/RF design:	Ben Duncan (BD Research)
Production Engineering in UK:	Paul Houlden & Associates (Houlden Law Fowler)

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