

Fig.7. Using the Figure 3 simulation circuit to analyse for C7, we see the capacitor is highly stressed not resistor R15 and badly chosen C7 can generate large distortion. When an amplifier is used for high frequency sinewave tests with or without load, this capacitor frequently fails open, disabling the Zobel, the amplifier may oscillate. Yet R15 is frequently specified as 3 watt rating and C7 ignored.

Fig. 8. Actual measured distortion of the 'stacked' metallised PET capacitor in the Self Blameless 50 watt class B design, at 8 watts power in an 8Ω load. Distortion will increase rapidly with increasing power output.

With 100 watts output into 8Ω at 20kHz, the capacitor must still withstand more than 28 volts while the resistor is subject to less than 2 volts or 0.6 watts. At such voltage a metallised PET capacitor can generate significant distortion. Fig 7.

My test equipment cannot generate that voltage so I measured C7 distortions using an eight volt signal and 100Ω source impedance, equivalent to 8 watts power output, representative perhaps of normal

listening. I measured a 0.1μF 'stacked' metallised PET capacitor, the unused spare for my 'Self' amplifier. At 8 watts output this capacitor generated -113.5dB third and -126.3dB fifth harmonic, distortions which would be reflected into the feedback network. Fig. 8.

Apart from this distortion, at 20kHz and 100 watts, this capacitor is subjected to more than twice the permitted sine wave rating for an Evox-Rifa MMK 0.1μF 63 volt

metallised PET capacitor while almost any resistor easily manages the less than 2 volt and 0.6w R15 dissipates. To minimise distortion in normal use and survive no-load sine wave testing, the capacitor choice for this network is important. I prefer a foil and Polypropylene or Polyphenylene Sulphide capacitor.

Input capacitor C1

Many designs use an unbiased 10-22μF polar aluminium electrolytic capacitor, C1, to input the signal and block unwanted DC from entering the power amplifier, assuming that if sized to ensure minimal signal voltage across the capacitor at low frequency, low distortion is guaranteed. That may well be correct provided the capacitor is not subjected to DC bias. More than a few volts bias will result in second harmonic distortion which will be amplified.

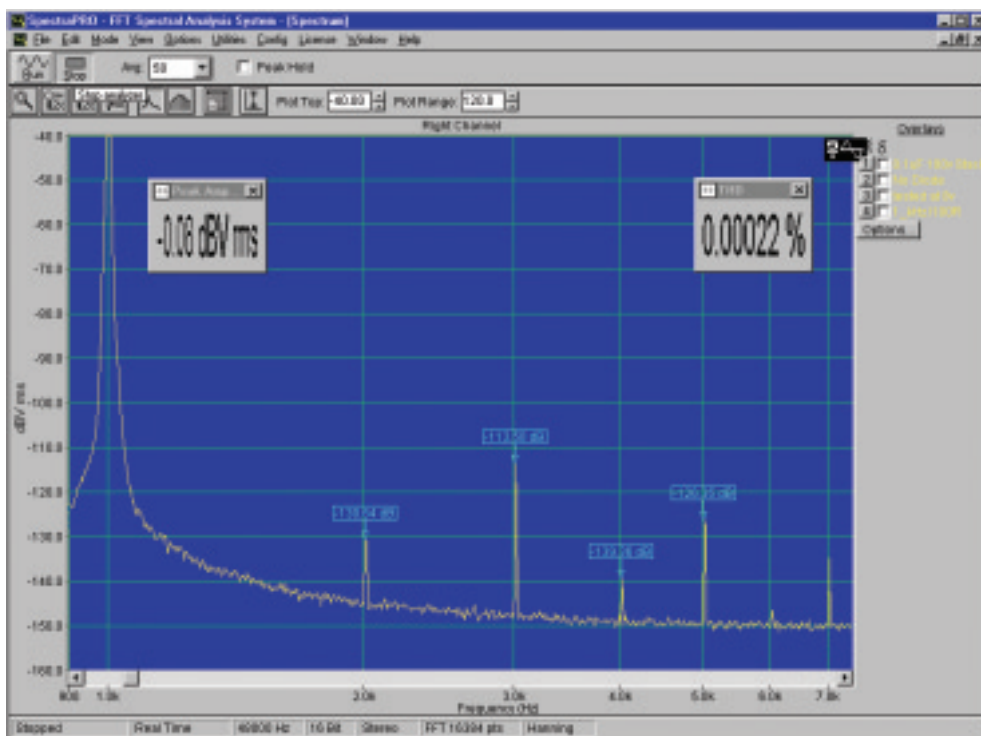
I believe a polar aluminium electrolytic capacitor is false economy since quite small metallised PPS or PET capacitors are available. Polypropylene capacitors produce much lower distortion but are larger and expensive. An inexpensive bi-polar electrolytic is small and produces little distortion unless subject to significant DC bias voltage. For the best performance use a film capacitor.

Class B bias stability networks

Many power amplifiers include another significant capacitor we should explore. Typically a 10-47μF is used to bypass the signal across the bias current stabilisation network. For values up to 22μF the lowest distortion most economic choice is a metallised PET style, closely followed by the 'double bi-polar' electrolytic capacitor⁴. For larger values, unless cost and size is no object, chose this electrolytic.

Many readers are familiar with the Douglas Self 'Blameless 50 watt class B' design, published in *Electronics World* February 1994. I have a pair, assembled on printed boards purchased from the magazine, which measured some 2.6 volts of DC bias voltage across their 47μF polar aluminium electrolytic capacitor C4, the bias current stabilisation network bypass capacitor.

Measurements of the AC voltage across C4, with the amplifier driven to 50 watts into 8Ω shows its AC voltage increasing significantly with frequency. At low frequencies, while the amplifier still has substantial open loop gain, this voltage remains small. As the amplifier open loop



gain reduces with increasing frequency, C4 is subjected to a significant signal voltage. At 10kHz I measured 1.15 volt AC using an AC coupled DVM to ignore the DC voltage. Any polar aluminium electrolytic capacitor subject to such AC voltage will generate very large second and third harmonic distortions.

The very best and quite expensive, specialist polar aluminium electrolytic capacitor of those I tested at 1 volt, generated some -93.2dB second and -100dB third harmonic with no bias. With 6 volt DC bias distortions increased dramatically, the second harmonic now -77.9dB. With 12 volt bias second harmonic increased tenfold to -72.9dB. Other polar aluminium electrolytics generated even more distortion when tested using a 1 volt signal.

The only cost effective, low distortion solution for this 1 volt signal level and DC bias voltage, is to use two double capacitance, 63 volt rated bi-polar aluminium electrolytic capacitors connected in series, the 'double bi-polar' configuration recommended in the last article of my first *Capacitor Sounds* series, *Electronics World* January 2003. Measured using 1 volt and no DC bias, this 'double bi-polar' capacitor combination measured -117dB second and -123dB third harmonic. With 6 volt bias, second harmonic became -102dB and -97.2dB biased to 12 volt DC as shown in this plot. An almost twenty times smaller distortion than measured using the best polar capacitor I tested, with or without bias. **Fig. 9**

Contrary to common belief, using an electrolytic well below its rated voltage does no harm, in fact it is beneficial, reducing leakage current, like choosing a more expensive, professionally rated, long life capacitor. Production electrolytic capacitors rated at 25-63 volt, provide better performance than lower and higher voltage types. In past years 'underunning' was frowned on because some badly designed electrolytes degraded the aluminium oxide dielectric. Subsequent application of rated voltage resulted in leakage current exceeding the maker's claim. Installed in circuit and underun for some time, a capacitor would not usually become subjected to rated voltage. Underunning never was a problem, rather a misunderstanding of capacitor and circuit behaviour.

Valve amplifiers

To date I have avoided discussing

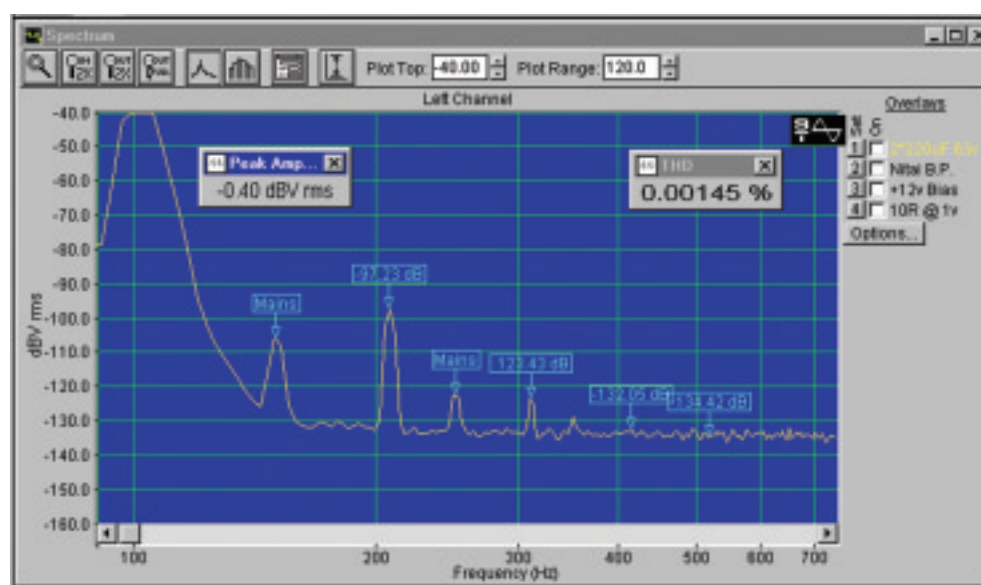


Fig. 9. Two 220 μ F 63 volt Nitai bi-polar capacitors in series made this 100 μ F "Double bi-polar" capacitor. Measured using a 1 volt AC and 12 volt DC bias as Figure 2, it generates almost twenty times less distortion. Second harmonic measured -101.75dB with 6 volt bias, -117dB unbiased.

valve amplifiers because I do not possess one and so cannot make any confirming measurements. However, I believe the DC blocking AC signal coupling capacitor used between a valve anode and subsequent grid, subjected to large DC bias and AC signals, can create distortion.

I decided to measure a specialist metallised Polypropylene 1 μ F 630 volt MKP capacitor⁵ and the 1 μ F paper capacitor reported in my August article, using a 6 volt test signal, the largest very low distortion signal I can generate across a 1 μ F capacitor using 100 Ω source impedance, with DC bias from 0 to 100 volt, then compare the results.

The MKP capacitor performed as well as expected, second harmonic increasing from -132dB with no bias to -123dB with 100 volt DC bias, a superb result. In contrast the paper capacitor behaved rather less well, illustrating perhaps why second harmonic distortion often dominates a valve amplifier output.

With no DC bias, second harmonic of this paper capacitor measured -128.8dB but biased to 30 volts DC its -116.5dB second harmonic was worse than the MKP at 100 volts. Biased to 100 volts this paper capacitor performed badly, generating an enormous -108dB second harmonic. Third harmonic for both capacitors changed little with bias, staying close to -130dB. Second harmonic distortion for this and similar paper capacitors increases with DC bias or AC signal voltage.

Fig. 10.

Power Rail Capacitors

The four polar electrolytic capacitors I exchanged for the bi-polar types included two 220 μ F power rail capacitors which are irretrievably linked with the power supply so cannot easily be evaluated in isolation. I plan to explore these as part of a future article.

In my next article, the last for this series, I measure distortions in low-level IC op-amp circuits and include a novel circuit technique that allows a modest op-amp to produce lower than usual distortion driving a low impedance load. In response to reader's requests, I also include a brief look at possible resistor and potentiometer distortions.

Conclusion

Having examined a variety of capacitor styles and their audio frequency distortions over the past two years, it is perhaps appropriate with the benefit of hindsight to summarise some findings.

For low level and pre-amplifier circuits but ignoring supply rail decoupling, most capacitors used will be small value and many will need

Table 3: AC and DC voltages measured on C4, with the amplifier set to generate 50 watts into 8R. This amplifier was assembled using printed circuit boards purchased from *Electronics World*.

Frequency	100Hz	1kHz	10kHz
DC bias volts	2.6v	2.6v	2.6v
AC signal voltage	0.095v	0.158v	1.15v

FFT Software

Throughout my *Capacitor Sounds* series except the first two articles, I used the SpectraPlus232 software for my distortion plots. This software is easy to set up and has served well. However some readers have asked whether lower cost software might be used, since a full set of options can become expensive.

I have now found two alternatives. Provided the reader can accept not having the on screen THD% display, all other facilities I used are provided by purchasing only the Spectra base module, almost halving the cost. The on screen THD% option can be purchased later.

My second alternative is 'WinAudioMLS Pro', I evaluated version 1.66, a new version having its microphone correction ability updated for use with my test equipment, or a conventional microphone. It can be obtained from the Dr. Jordan web site.

As standard this software provides a THD+N display and cursor controlled readout of harmonic levels. It accepts the microphone correction file, essential when using my notch filter/preamplifier assembly. In addition to all the features needed for my measurements it also provides an MLS measuring facility. This can be used to measure loudspeaker and room responses as well as the impedance and phase of low impedance components, especially those used in loudspeakers. All this for less cost than for the basic SpectraPlus232 module, makes this software well worth your evaluation.

This software also has a range of additional upgrade options, but I found the base WinAudioMLS Pro version with their THD% option, sufficient for my needs.

Contact

WinAudioMLS Pro

<http://www.dr-jordan-design.de>

SpectraPlus232

<http://www.soundtechnology.com>

1% tolerance. For values up to 47nF we have a choice of near perfect, very low distortion, extended foil and Polystyrene or extended foil and Polypropylene capacitors, available at 1% in both axial lead and 'tombstone' styles. COG ceramic capacitors at 5% tolerance, as low cost discs for small values and multi-layer capacitors to 100nF, are distributor items. Larger capacitance values and closer tolerances are manufactured. COG ceramic provides low distortion, unsurpassed capacitance stability with voltage, temperature, time and frequency, the almost perfect capacitor.

For values of 100nF and above, we could use multiples of the above types but foil and Polypropylene styles are available to 10µF, regardless of DC bias they assure very low distortion. Metallised PPS types produce little distortion unless subject to significant DC bias. Available to 10µF and 1% tolerance, PPS capacitors provide excellent temperature and long-term capacitance stability in smaller case sizes than Polypropylene types.

Power amplifiers needing larger value signal path capacitors, should use bi-polar aluminium electrolytic capacitors, avoiding the conventional polar aluminium electrolytic capacitor for audio signals. With signal voltages across a large

capacitor of 0.5 or more volts, the 'double bi-polar' aluminium electrolytic capacitor, two double value conventional bi-polar aluminium electrolytic capacitors in series, is demonstrably the most economic low distortion choice. Many writers advocate using lesser value film capacitors, to bypass a polar aluminium electrolytic capacitor to reduce its distortion. My measurements show this has little effect, compared to using the bi-polar style, which produces much lower distortion at less cost.

Distributor stocks of bi-polar aluminium electrolytic capacitors rarely exceed some 470-1000µF at low voltage, this results from customer demand and not capacitor technology, manufacturers will respond to market demand as will distributor stockholdings.

More than 30 years ago I developed a range of bi-polar or *reversible* electrolytic capacitors up to 10,000µF at 63 volt and the Erie Company manufactured many thousands. The largest example which I still have today, a 2,000µF 100 volt in a 115 x 45mm case, was developed as the output coupling capacitor for a very high power audio amplifier. ■

References

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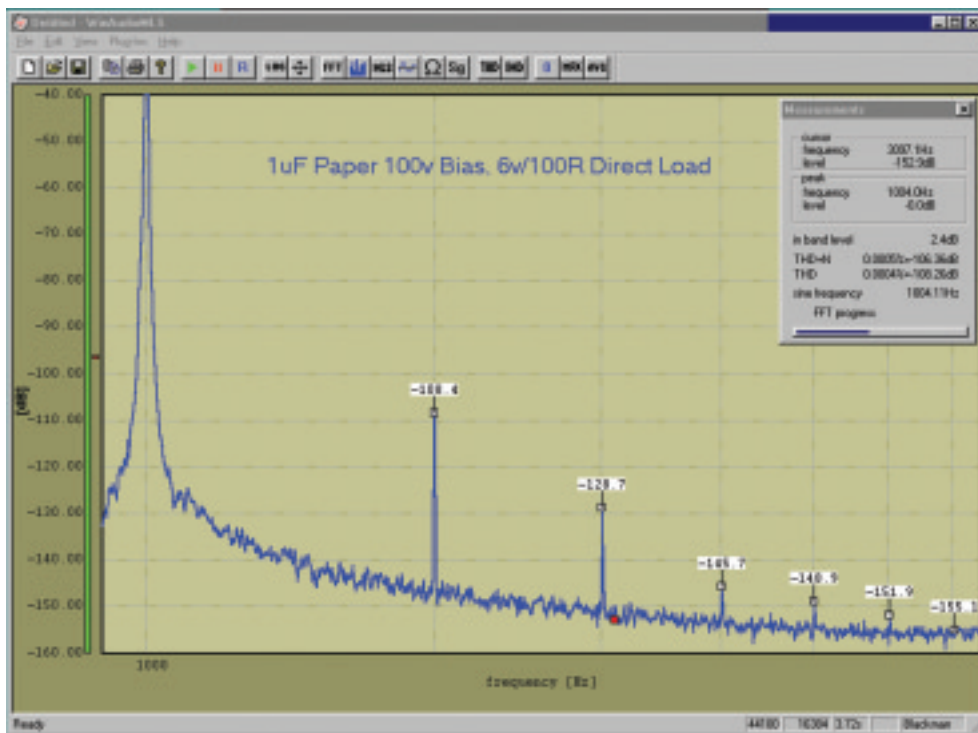


Fig. 10. A typical 1µF paper capacitor, with 6 volts AC at 1kHz and 100 volt DC bias, produced this excessively large second harmonic distortion. The 630 volt 1µF MKP Polypropylene capacitor was five times better with second harmonic - 123dB, third -130dB, just 0.00008% distortion. This plot was measured using the Dr.Jordan software, the SpectraPlus232 gave almost identical results.