Capacitor Sounds II - Op-Amp and Resistor Distortions.

This article, the last of the Capacitor SoundsII series, was prepared for the December issue of Electronics World.

Having completed the design for my very low distortion fixed output oscillator, part of the equipment for my original Capacitor Sounds series, I needed to provide a variable level output, able to develop an undistorted 6v test signal across my near perfect 1µF reference capacitor. My original potentiometer and non-inverting unity gain output amplifier design distorted badly driving a 3v signal into a 600Ω resistive load. This problem was solved by using an NE5534AN op-amp as a variable gain inverting amplifier, with a 15k4Ω input resistor and a 25kΩ conductive plastic potentiometer for feedback. This inverting, variable gain output stage and potentiometer, added almost no measurable distortion driving a 600Ω resistive load, but did distort with a capacitive load.

Clearly for my capacitor measurements, I needed to design a very low distortion, more powerful, output buffer stage. Searching my bookshelves and back issues of Electronics World I found nothing, but on Internet I found a short series of articles by Walt Jung, "Op-Amp Audio" originally published in the US magazine Electronic Design, from September to December 1998 **REF.1**. In this he suggests using a gain stage and separate output buffer. Apparently he had successfully used the Analog Devices AD811AN, a current feedback video amplifier, as an audio output buffer. Using an OPA134 gain stage with this AD811AN output, I could develop an undistorted 6v signal at 1kHz across my near perfect 1µF reference capacitor from 100Ω source impedance.

A similar test signal at 100Hz across larger capacitors, needed more current than the 100mA the AD811AN could provide. Further searching found a novel circuit for an exceptionally accurate, active feedback amplifier developed as buffer input to a 16 bit ADC, again in Electronic Design, April 2001 **REF.2**. A similar arrangement would drive the more powerful output stage needed for my 100Hz test equipment. **REF.3** At that time, busy developing circuits and measuring capacitor distortions, time did not permit exploring these solutions in more detail for general use. Now two years later, using my standalone distortion tester, **REF.4** I could at last begin. **Fig. 1**

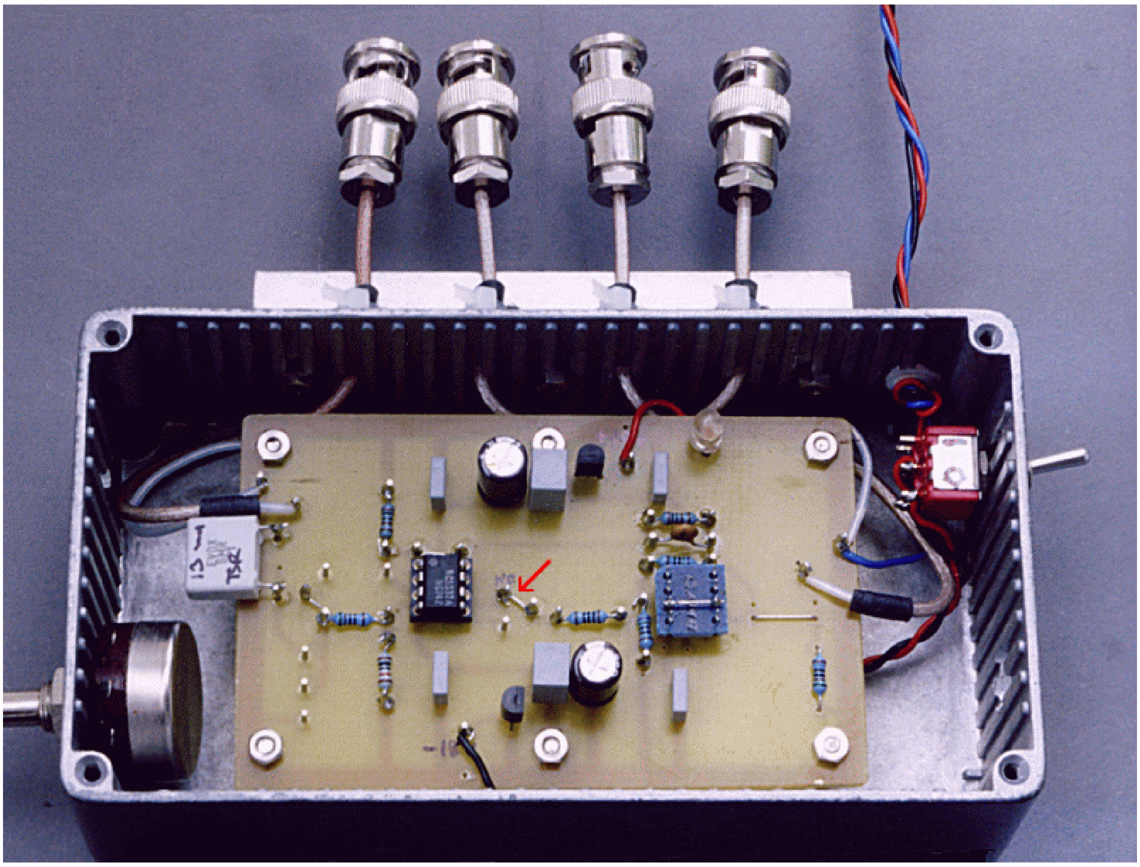


Figure 1) This test PCB, attached to my real-time hardware distortion analyser, was used for more than 75 distortion measurements of the IC Op-Amps and test circuits in this article, simply by unplugging IC's.
Switching the link shown arrowed, changes from the 'dual' amplifier position shown to 'single' now using the 'A' section only of the IC. Replacing the DIL header with an IC, changes from measuring U7, single or dual, to the two amplifiers U7 and U8.

Active Feedback Amplifier.
Many low level audio systems use unity gain, voltage following IC's as buffers between stages, it being often claimed such circuits can output up to 10v AC using ±15v supply rails, but measurable distortions are produced with much smaller signals. This novel active feedback amplifier, developed as a 16 bit input buffer, used both sections of a dual op-amp, the first amplifier section to drive the load as usual, the second stage to provide distortion cancelling active feedback instead of the usual feedback resistor. The idea being that having two errors of equal value but opposite sign, the feedback signal error would cancel the forward gain error **REF.2.** **Fig. 2**

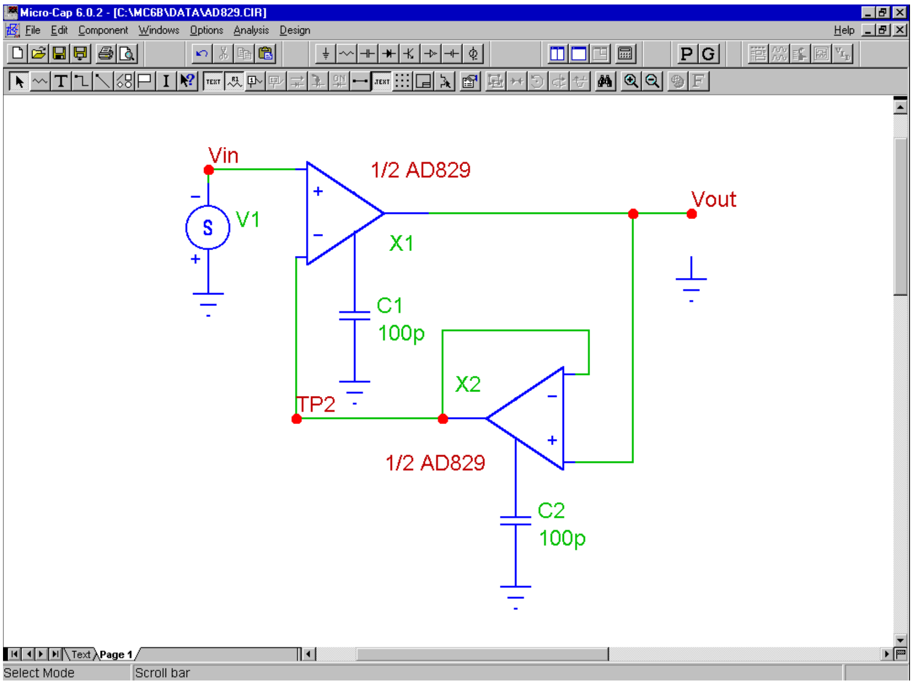


Figure 2) The schematic from the "Active Feedback Amplifier Enables High-Performance A-to-D Conversion" article **REF.2** found while accessing the Electronic Design web site.
Initial tests measuring the input - output voltage differential of an AD712JN using my differential scope probe **REF.5** confirmed this arrangement did reduce errors.

Intended for use as a unity gain buffer, I wondered whether it could be adapted for use in the gain of two buffer I now needed. A few initial measurements while developing my 100 Hz buffer confirmed this arrangement could provide gain and improve performance. Initially it seemed an almost ideal distortion reducing panacea, except that some IC's I tried did not work at all well in my gain of 2 circuit.

Op-Amp distortion tests.
Most op-amps provide very large open loop gain, typically 100dB at low frequency, allowing use of substantial feedback to reduce distortion. However this gain reduces rapidly with frequency such that by 1kHz, open loop gain has reduced 20dB and another 20dB by 10kHz increasing output distortion. With small audio signals and light loading this may not present a problem but with increasing amplitude and heavier circuit loading problems do emerge, as I found when generating my distortion free 1kHz signal in a 600Ω resistive load. Capacitance to ground compounds these difficulties and can result in oscillations.

The 'direct' input to my notch filter presents a high resistance in parallel with a 10n2F capacitance, which with the 600 Ω load to ground in my test PCB **REF.6** provides a difficult 575Ω and parallel 10n2F test load, exceeding that expected in an audio circuit. I decided to use this load to explore how popular audio op-amps behaved. Would using the second stage of a dual IC as an output buffer or the Walt Jung external buffer, permit larger amplitude undistorted signals?

To make certain of a stable performance at all signal levels, I decided to use my test PCB to measure distortion with a 1v test signal, then increase the signal in 1v steps to 6v or until the amplifier overloaded.

Fig. 3

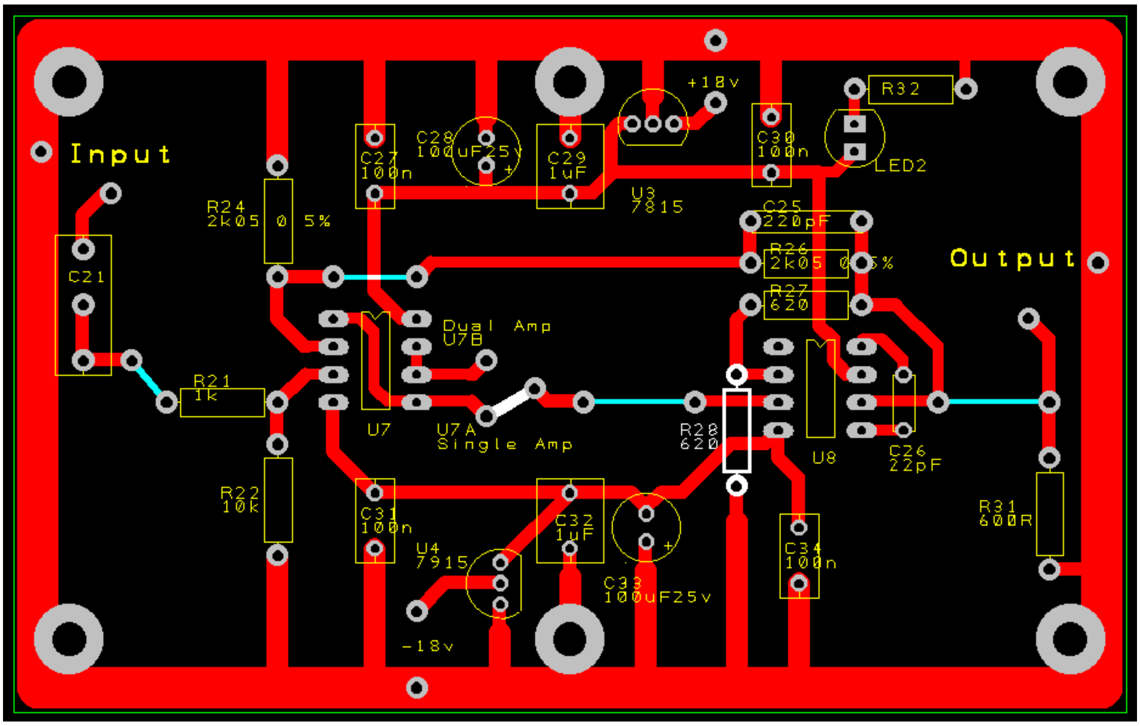


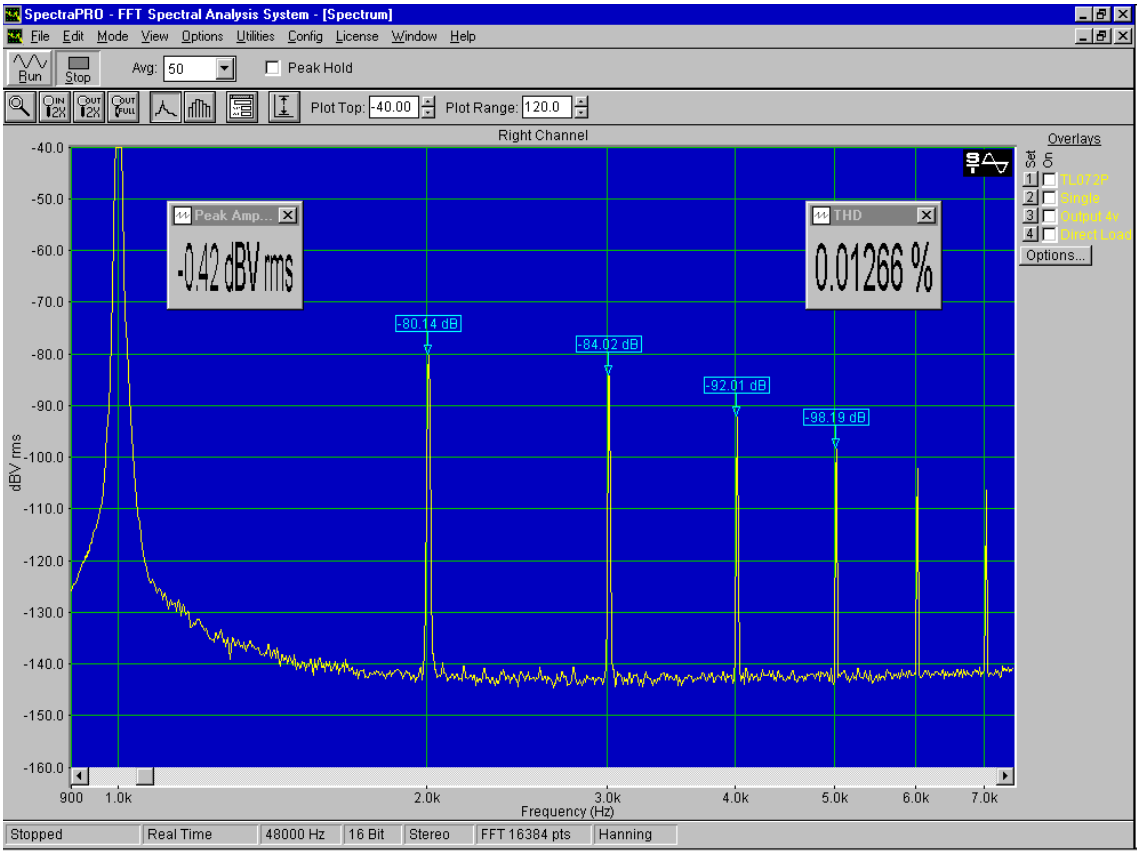
Figure 3)
The test PCB and component values used for this article. The link which changes from measuring the 'Single' to 'Dual' configurations is highlighted in white.

Resistor R28, also highlighted in white, must be removed when using an NE5534AN or similar amplifier also the DIL header for U8.

With a current feedback IC, such as the AD811AN for U8, resistor R28 is required, so should be refitted.

Single Amplifier circuit.

For many years the TL072CP, MC4558TPI and NE5532AN dual amplifier IC's have been used in audio systems. With a DIL header to bypass U8 and taking my output from U7A to use just one half of a TL072CP, its unloaded second section simply voltage following the first section's output, I wanted to see what low distortion signals with a gain of 2, could be driven into my test load. **Fig. 4**



Avg: 50

☐ Peak Hold

Plot Top: -40.00

Plot Range: 120.0

Peak Amp... -0.42 dBV rms

THD 0.01266 %

Stopped | Real Time | 48000 Hz | 16 Bit | Stereo | FFT 16384 pts | Hanning

Figure 4) Single amplifier distortion measured using the 'A' section of a TL072CP driving into my 575Ω 10n2F test load.

Unable to drive a full 4v into my test load, for this IC the 4v nominal test voltage had to be reduced slightly to 3.8v.

The other two IC's worked rather better, the MC4558TPI producing 0.00228% distortion at 4v, but the NE5532AN was seven times better, just 0.00032% distortion driving a 4v signal into this difficult test load, the best of these older style op-amps .

From earlier measurements I already knew the expensive AD797 can provide large amplitude very low distortion signals, but for this article I wanted to explore less exotic devices.

To minimise distortion with any IC it is essential to match as closely as possible the impedances 'seen' at its inverting and non-inverting inputs, otherwise it will generate increased second harmonic distortion, as explained in the Walt Jung papers. The AD797 is able to produce exceptionally low distortion but is also sensitive to small impedance differences between its inverting and non-inverting inputs.

Although not claiming any particular distortion performance, in the past I found the BiFET AD712JN behaved well when driving adverse loads. Tested as above I measured 0.00162% distortion, rather better than the MC4558TPI and TL072CP but worse than the NE5532AN. A JFET input TLE2072CP measured 0.00142%, much better than the old TL072CP and slightly better than the AD712JN.

An OP275G with its Butler Bi-polar/JFET input stage intended for audio circuits, measured 0.00088% distortion. The Burr Brown FET input OPA2134CPA, part of their 'SoundPlus' range designed for low distortion audio was much better, I measured 0.00036% to effectively equal the NE5532AN measured performance. **Fig. 5**

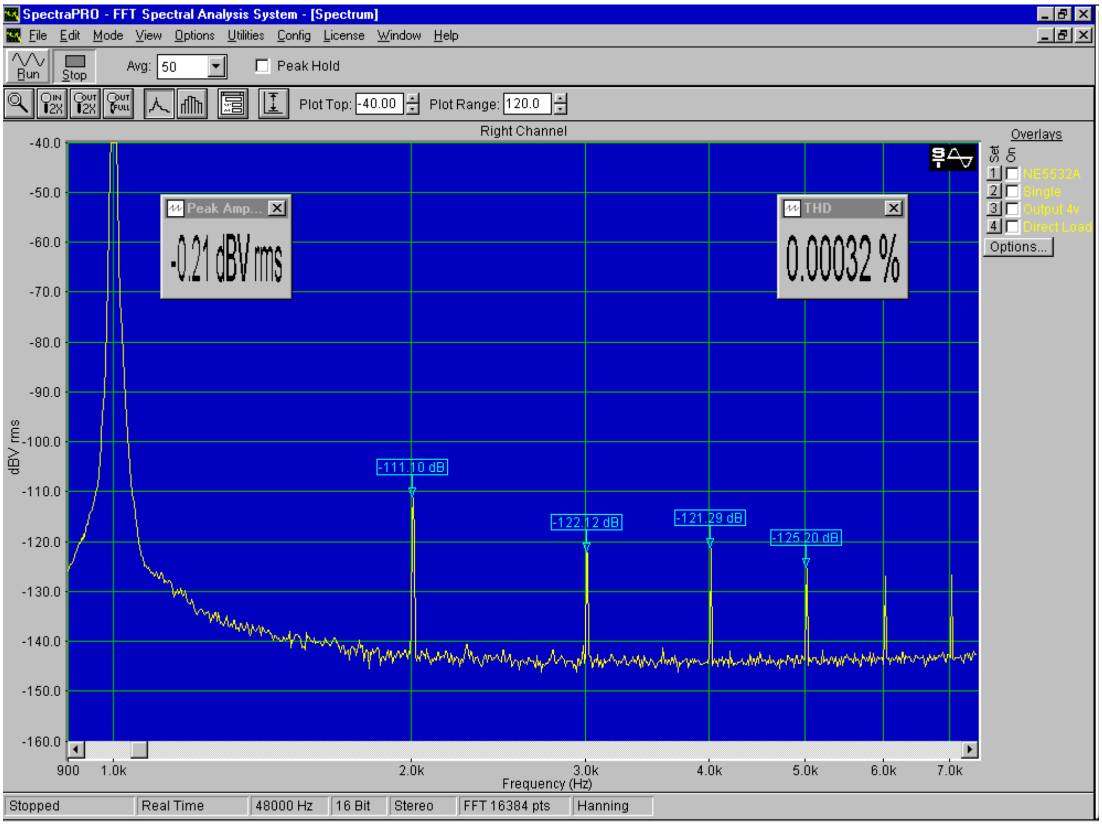


Figure 5)
Tested at 4v output, but otherwise exactly as Figure 4, this 'single' amplifier test of an NE5532AN produced remarkably little distortion driving this difficult test load.

A considerably heavier loading than would be expected in any real world circuit or interconnect cable loading.

Dual Amplifier.
Having established a distortion baseline for a single stage amplifier driving 4v into my test load, would a gain of two version of the dual amplifier active feedback design, with output now taken from U7B, work any better. The heavy output currents would be removed from the input gain stage, but being in the one package, would thermal or capacitive feedback present new problems, increase distortions or even result in oscillation?

I decided to start by trying the worst performing of the above amplifiers, for that should more clearly show any improvement, as reduced distortion or increased drive level. The TL072CP in this 'Dual' arrangement could not provide increased drive, but distortion at 4v output reduced dramatically from 0.01266% to 0.00041%, almost equalling the best of the dedicated 600Ω capable audio op-amps.

Fig. 6

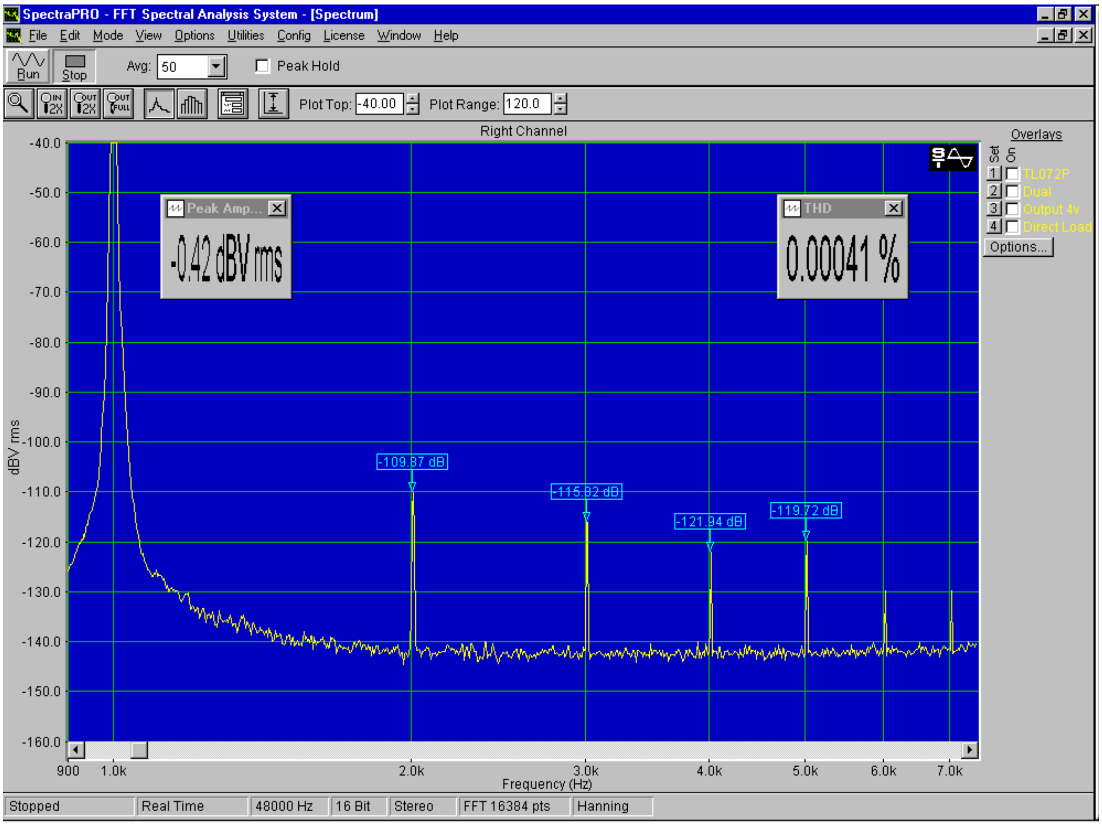
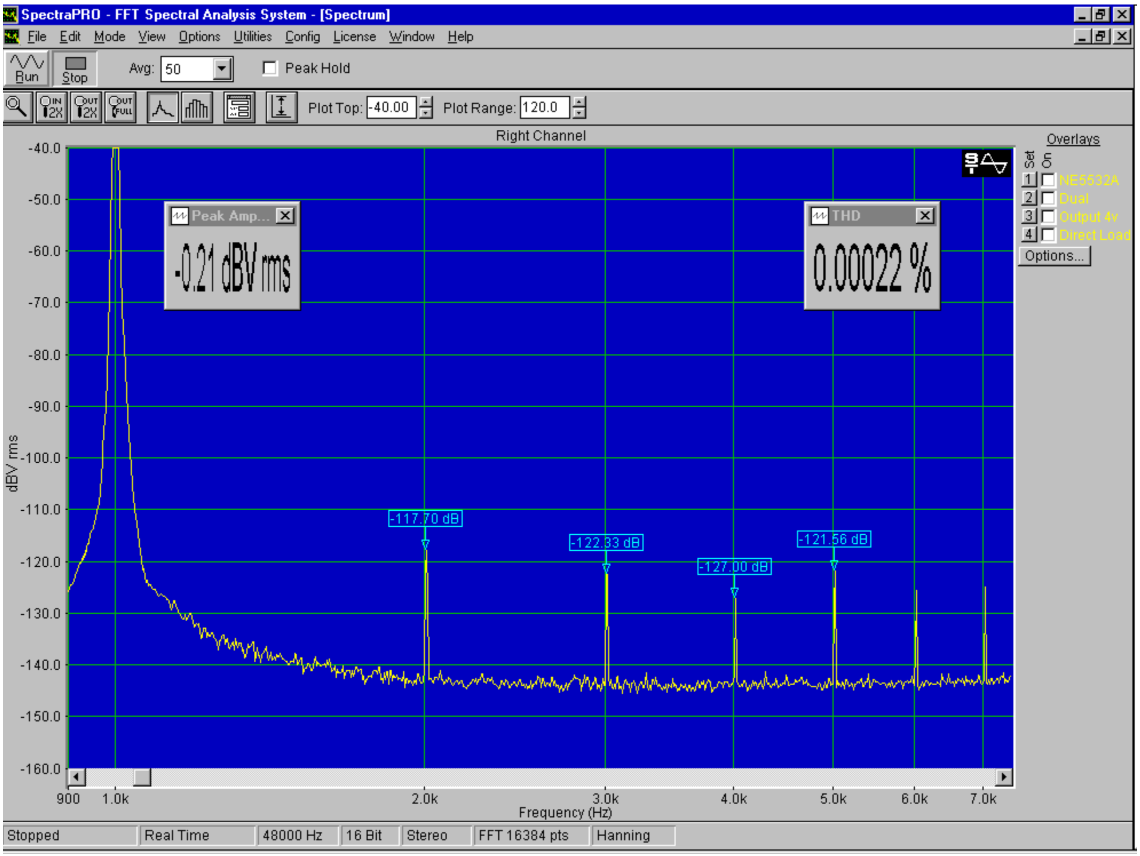


Figure 6)
The TL072CP of Figure 4, tested in the 'dual' amplifier circuit using its 'A' half for gain and 'B' half as a voltage follower driving the test load.

Distortion has dramatically reduced from 0.01266% to 0.00041%.

With such a dramatic improvement, I wondered how the other op-amps would perform using this circuit and components by simply plugging in a different IC. Strangely the MC4558TPI, which had easily outperformed the TL072CP in my first tests, also improved but by a far smaller margin, from 0.00228% as a single stage to 0.00062% in this dual circuit. However this IC could now almost drive a low distortion 5v signal into my load.

The NE5532AN also improved from its original, equal best single stage performance, to an amazing 0.00022% at 4v, almost halving the best single stage results. In addition it could now easily drive a full 5v low distortion signal into my test load. In like fashion the AD712JN also could drive a 5v signal at 0.00073% and a 4v signal with just 0.00032% distortion. **Fig. 7**



SpectraPRO - FFT Spectral Analysis System - [Spectrum]

Avg: 50 ☐ Peak Hold

Plot Top: -40.00 Plot Range: 120.0

Peak Amp... -0.21 dBV rms

THD 0.00022 %

Overlays
Set On
1 ☐ NE5532A
2 ☐ Dual
3 ☐ Output 4v
4 ☐ Direct Load

Stopped | Real Time | 48000 Hz | 16 Bit | Stereo | FFT 16384 pts | Hanning

Figure 7) Re-testing the Figure 5 NE5532AN now using the ‘dual’ amplifier test circuit as Figure 6, distortion has reduced again to 0.00022%, 50% less than the best ‘single’ amplifier of those tested.

Whether a feature of the op-amps themselves or my test circuit, the TLE2072CP, OPA2134CPA and OP275G were totally unusable in this configuration, so after all it has failed to become the hoped for universal palliative. Exactly why some IC’s performed so well in this circuit and others were unusable is not clear.

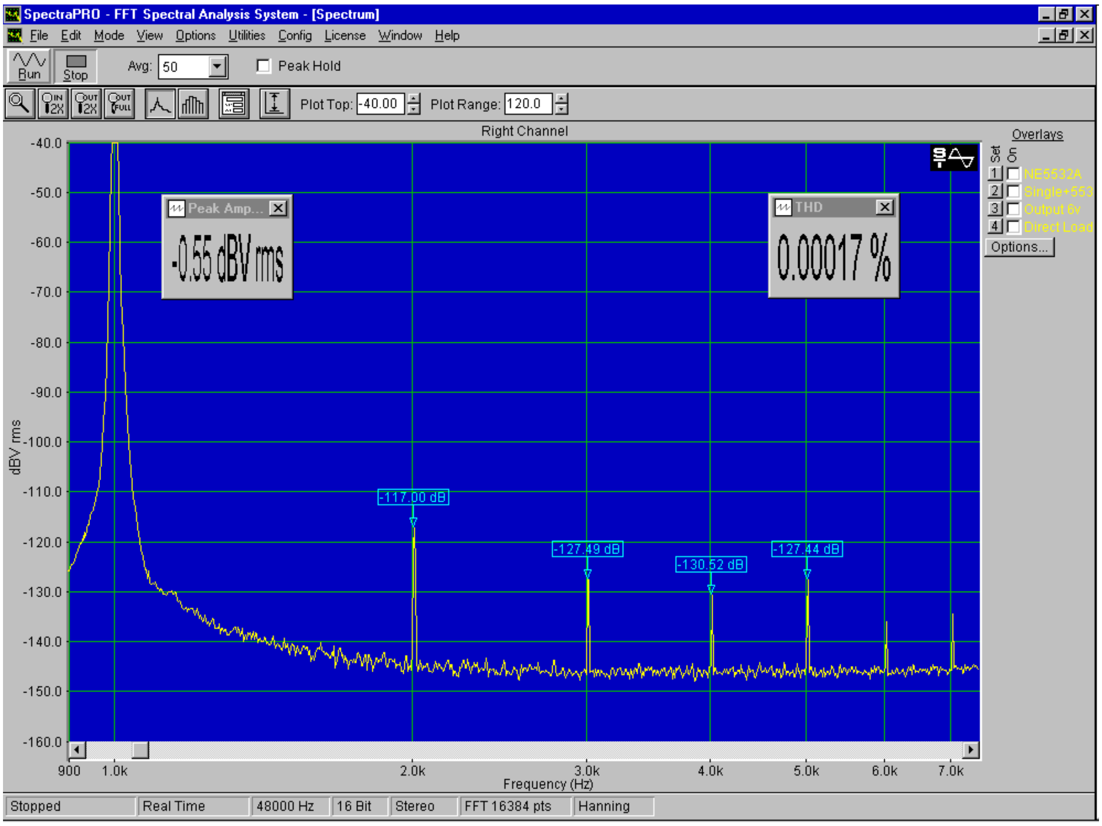
Perhaps using an external load bearing buffer op-amp as proposed by Walt Jung would work better. This two IC arrangement is more expensive and requires larger printed board area, but in small quantities it could prove less expensive than using say a single AD797 . I decided to explore this option, using the identical test set up, test load and PCB test circuit by replacing the bypass DIL header with an IC. I knew the AD811AN worked well in this circuit position, but would an NE5534AN perform ?

Two amplifiers.

Starting with a 1v test signal and increasing in 1v steps as before, I tried an NE5534AN as the output stage with various amplifier gain stages. With R28 removed the NE5534AN output stage worked as a unity gain voltage follower. Taking output once more from U7A, the ‘A’ section of the first op-amp provided the gain of two. Its unloaded second section following the first section output but was otherwise inactive. Using the NE5532AN as the first amplifier, at each test voltage significantly less distortion was measured compared with the same NE5532AN used alone, whether as a single amplifier or in my dual configuration.

Furthermore, with the drive signal into my test load increased to 6v I measured just 0.00017% distortion. At all lower test voltages, a similar or slightly lower distortion was measured, an amazing result. Clearly removing the output stage’s thermally conducted heat from the gain stage was beneficial in reducing distortion. **Fig. 8**

Even more amazing the TL072CP which had performed less well on its own, with the NE5534AN output, was able to drive a 5v signal into the load with only 0.00044% distortion. The MC4558TPI also improved and was able to drive a 6v signal at 0.00031%. With this success I decided to refit R28 so I could use an AD811AN output buffer to compare directly with these NE5534AN results.


SpectraPRO - FFT Spectral Analysis System - [Spectrum]

Avg: 50 ☐ Peak Hold

Plot Top: -40.00 Plot Range: 120.0

Peak Amp... -0.55 dBV rms

THD 0.00017 %

Overlays: 1 ☐ NE5532A; 2 ☐ Single+553; 3 ☐ Output 6v; 4 ☐ Direct Load

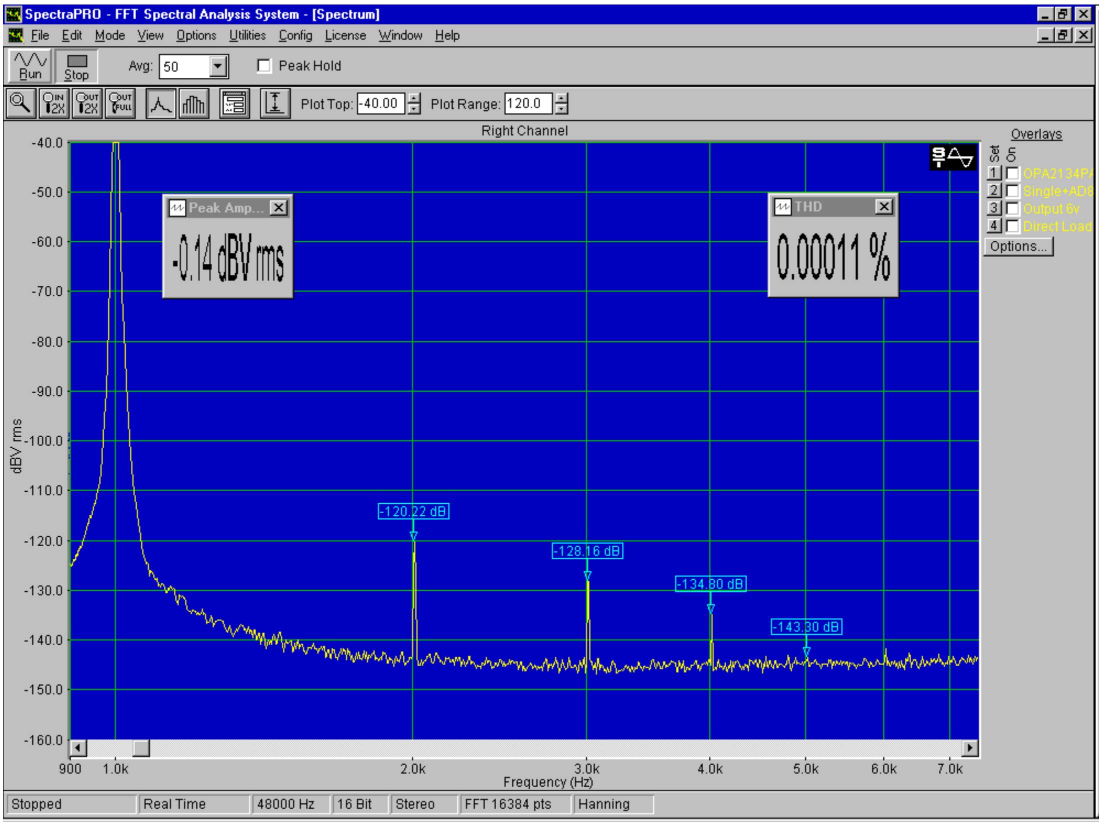
Stopped | Real Time | 48000 Hz | 16 Bit | Stereo | FFT 16384 pts | Hanning

Figure 8)
Removing the DIL header and R28 to now use two separate IC's rather than the 'dual' arrangement of Figures 6 & 7.

Testing the Figure 5 NE5532AN 'A' section with an NE5534AN for U8 removed the test load thermal effects, reducing distortion to just 0.00017%, halving that measured with the best performing 'single' IC.

The NE5532AN which had worked so well with the NE5534AN output buffer, partnered now with the AD811AN generated 0.00308%, ten times more distortion than when measured as a single amplifier. Since this was the last but one combination of those tested and the final combination worked perfectly, this distortion must result from a particularly unhappy combination of IC and test load characteristics.

However all other combinations I tried worked extremely well with this AD811AN and 5v output. The TL072CP improved to 0.00022% distortion, half that found when this IC was used with an NE5534AN. The OP275G and MC4558TPI improved more to 0.00016% and 0.00014% distortion respectively. Best of all, the OPA2134CPA with this AD811AN output, measured a remarkable 0.00010% at 5v output and could even manage 0.00011% distortion at 6v output, approaching the distortion measuring limit of my equipment. **Fig. 9**


SpectraPRO - FFT Spectral Analysis System - [Spectrum]

Avg: 50 ☐ Peak Hold

Plot Top: -40.00 Plot Range: 120.0

Peak Amp... -0.14 dBV rms

THD 0.00011 %

Overlays: 1 ☐ OPA2134P; 2 ☐ Single+AD8; 3 ☐ Output 6v; 4 ☐ Direct Load

Stopped | Real Time | 48000 Hz | 16 Bit | Stereo | FFT 16384 pts | Hanning

Figure 9)
Re-fitting R28 and using an AD811AN current feedback amplifier for U8.

This Burr Brown OPA2134CPA , the joint best 'single' amplifier tested, reduced its distortion from 0.00036% at 4v output to this remarkable 0.00011% distortion and 6v output.

Op-Amps - Conclusions.

Clearly while the dual amplifier arrangement worked well, usually very much better than using a 'single' amplifier, following the Walt Jung advice **REF.1** to physically separate the gain and output driver stages can produce exceptionally low distortion figures into an adverse load, for many perhaps most combinations of gain and driver IC's.

Resistors.

Many readers have written requesting advice about the resistor distortions, much publicised in magazines and Internet discussion groups and based on subjective tests, not measurements. Concerned about voltage and temperature coefficients and the effect of magnetic and non-magnetic leadwires.

I believe distortion from carbon composition and to a lesser extent carbon film resistors can be a problem, but expect modern laser spiralled 1% metal film resistors would not produce any measurable distortion with my equipment. Today no sensible audio design would use carbon composition or carbon film resistors.

Every resistor exhibits a temperature coefficient and a very small voltage coefficient, specified according to international standards and test methods. BS and CECC specifications demand 'true values', so test instrument uncertainties must be added to the components measured values in any published claim. Consequently a resistor specified as 50ppm temperature coefficient, may in practise exhibit less than 30ppm deviation.

In circuit, resistor body core temperature will increase above local ambient according to the power dissipated. The body temperature of a typical 0.25W resistor with 25% rated loading, increases some 6°C above local ambient, but temperature coefficient with a steady temperature rise does not produce distortion. To generate distortion with an AC signal, resistor core temperature must track the AC signal. Every resistor has some mass and thermal inertia, its core temperature cannot instantly change. Metal film resistor temperature and voltage coefficients with modest AC signal loading, generate little or no measurable second harmonic distortion, even with low frequency signals.

In past years when 5% carbon film resistors were standard, miniature high speed grinding wheels were used to cut a groove in the resistive film to trim to value. The resultant spiral cut through the resistive element, into the surface of the exceptionally hard resistor core, usually had ragged edges and varying width. In places a poor grind could leave minute semi-conducting bridges across the cut, resulting in increased third harmonic distortion. Today 1% tolerances require laser cutting equipment. Lasers cut clean, consistent, spirals, virtually eliminating this source of distortion.

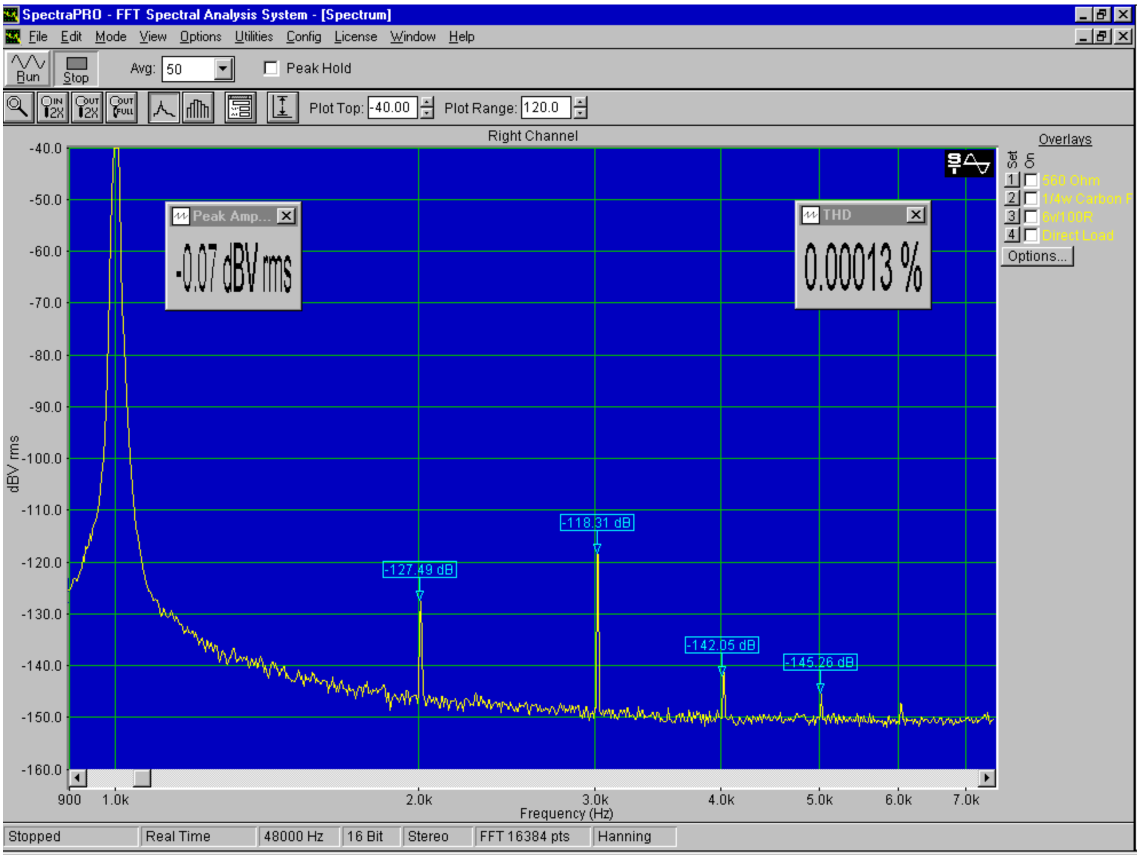
The termination between lead wire and resistor element for almost all low wattage resistors relies on a pressure contact between the end cap and the resistor element. Unless adequate contact can be assured after soldering the resistor into circuit, this presents a potential source of third harmonic distortion. Some audio specialist companies have used non-magnetic end caps to counter the 'magnetic' discussions. To maximise the contact pressure it is essential the thermal expansion coefficients of end cap and resistor body are matched using a high tensile strength, elastic metal. For these reasons I prefer to use plated steel end capped resistors with tinned copper leadwires, believing any magnetic field effects due to the tiny currents in most resistors, flowing through this end cap, are preferable to third harmonic distortion from poor end contact pressure.

My equipment can only stress a resistor to some 6v and read distortions above -120 dB. To stand any chance of realistically measuring distortions in 1% metal film resistors, much larger pure test voltages, loading the resistor to perhaps 50% power and measurements down to -135dB or better is needed.

I no longer have any carbon composition resistors but do have a number of 20 years old, ground spiral, carbon film resistors. I decided to see whether my test equipment might find these produced more distortion than modern low cost 1% metal film types. Using a 6v test signal I measured some 56KΩ using 1kΩ source impedance, 5k6Ω also using 1kΩ source and finally some 560Ω resistors using 100Ω source impedance. Naturally resistor current through the 56kΩ parts was minuscule so it was no surprise to find all types, carbon film and metal film measured almost identically, near my equipment's basic distortion.

At 5k6Ω I found one particular carbon film resistor measured 0.00011% compared with the metal film types at 0.00007%. At 560Ω, because the resistors were passing 10mA through current and dissipating 65mWatts, larger differences were noticed. I now found two carbon film resistors measuring increased distortion. One, a quarter watt part measured 0.00013% and a half watt 0.00010%. In comparison low cost 1% metal film resistors measured 0.00007% as did a 0.5% Welwyn RC55, near the baseline distortion of my equipment, at these settings.

Second harmonic for all four resistors measured -127dB, the metal film third harmonics measured -125dB while the carbon film third harmonics measured -118 and -120dB respectively, higher harmonics remained below -140dB for all types. **Fig. 10**


SpectraPRO - FFT Spectral Analysis System - [Spectrum]

Avg: 50

☐ Peak Hold

Plot Top: -40.00

Plot Range: 120.0

Peak Amp... -0.07 dBV rms

THD 0.00013 %

Overlays

1 ☐ 560 Ohm

2 ☐ 1/4w Carbon F

3 ☐ 6v/100R

4 ☐ Direct Load

Stopped | Real Time | 48000 Hz | 16 Bit | Stereo | FFT 16384 pts | Hanning

Figure 10) This 20 years old 1/4 watt carbon film resistor made with a ground, not laser trimmed, spiral, produced 0.00013% distortion when loaded to 25% rated power.

The second harmonic for a same make 1/2 watt resistor loaded to 12.5% rated power measured 2.3dB better. Distortions from a modern laser spiralled, low cost 1% 1/2 watt metal film resistor, were too small to be measured using my equipment.

Fixed Resistors - Conclusions.
Provided a resistor is loaded to 25% of its rated power or less, modern 1% metal film resistor distortion is small, typically less than 0.0001%, less than almost any other active or passive component, which may be used in an audio system.

Distortions found with the 1% metal film resistors used for this article are small and cannot be properly measured at 6v using my less than 1ppm distortion equipment.

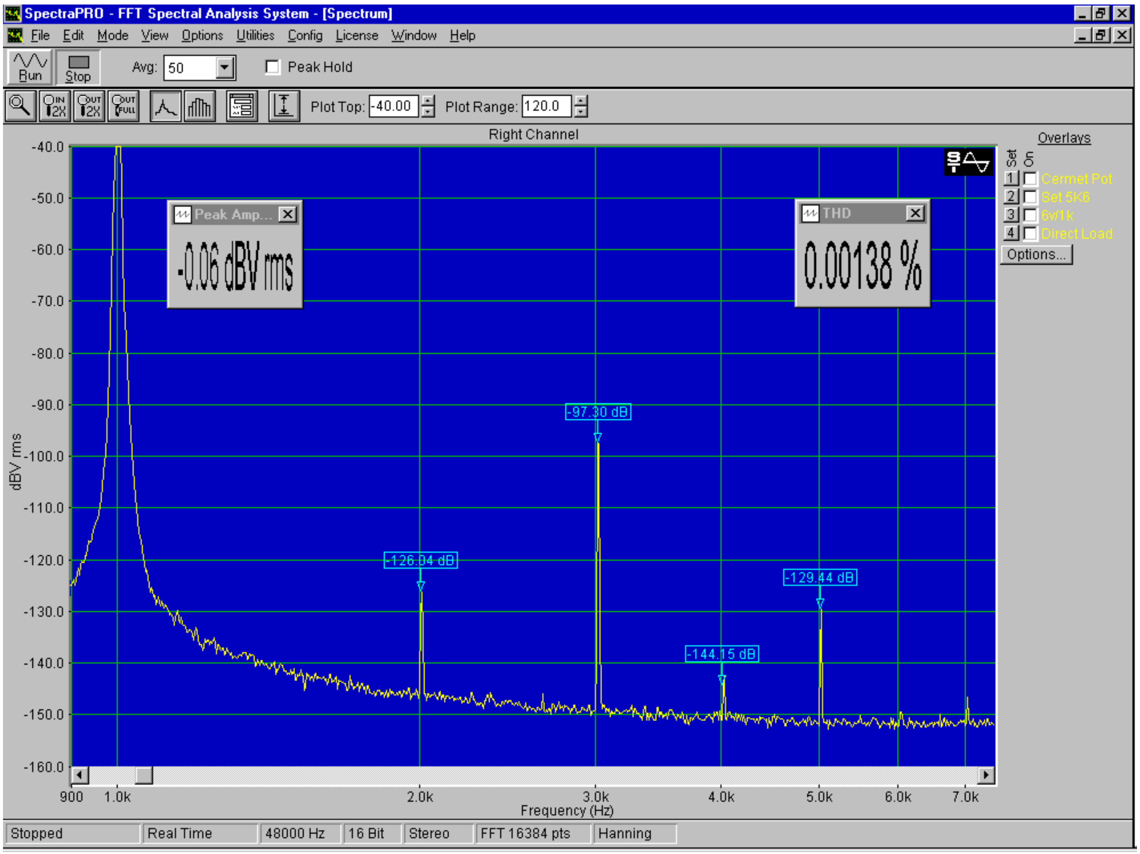
Volume controls - trimmer resistors.
Almost as many words have been written about noisy carbon volume controls as for distorting capacitors, but I have seen little about distortion from volume controls or pre-set trimmers. As seen in this series, third harmonic distortion in capacitors and resistors is usually caused by non-Ohmic contact resistances, surely the wiping contacts used in volume controls and pre-set trimmers must produce similar distortions. Recalling the problems I had with my original oscillator variable output stage, I decided to explore further.

Unlike other variable resistor types, a multi-turn wire wound at AC will exhibit a reactive phase angle in addition to its claimed DC resistance value. Depending on its design, construction and the test frequency, it may appear either as inductive or capacitive. I tested my stocks and without exception all were capacitive at low frequencies, measuring typically 100pF, becoming inductive at higher frequencies. This reactance may cause problems in some circuits.

Using the 6v drive at 1kHz from my equipment, I first connected some 10kΩ potentiometers and multi-turn pre-set resistors to make 5k6Ω variable resistors, passing some 1mA through each wiper. I used a 10 turn wirewound, a 20 turn cermet trimmer, a low cost carbon and a conductive plastic volume control. Not surprisingly the 10 turn wirewound measured 0.00007%, my equipment baseline distortion, the conductive plastic was almost as good at 0.00009%, the difference being a 5dB increase in third harmonic distortion.

When I tried the low cost carbon volume control I expected and found increased distortions, now measuring 0.00129%, 14 times greater distortion than the conductive plastic volume control. Second harmonic was -117dB, third -98dB, fourth -137dB and fifth -121dB.

Finally the multi-turn cermet trimmer which measured an enormous 0.00138% distortion, worse even than the inexpensive carbon control. While the second and fourth harmonics remained near my measurement baseline, its -97dB third harmonic dominated distortion, more than 31dB worse than measured on the wire wound control. **Fig. 11**


SpectraPRO - FFT Spectral Analysis System - [Spectrum]

Avg: 50

☐ Peak Hold

Plot Top: -40.00

Plot Range: 120.0

Peak Amp... -0.06 dBV rms

THD 0.00138 %

Stopped | Real Time | 48000 Hz | 16 Bit | Stereo | FFT 16384 pts | Hanning

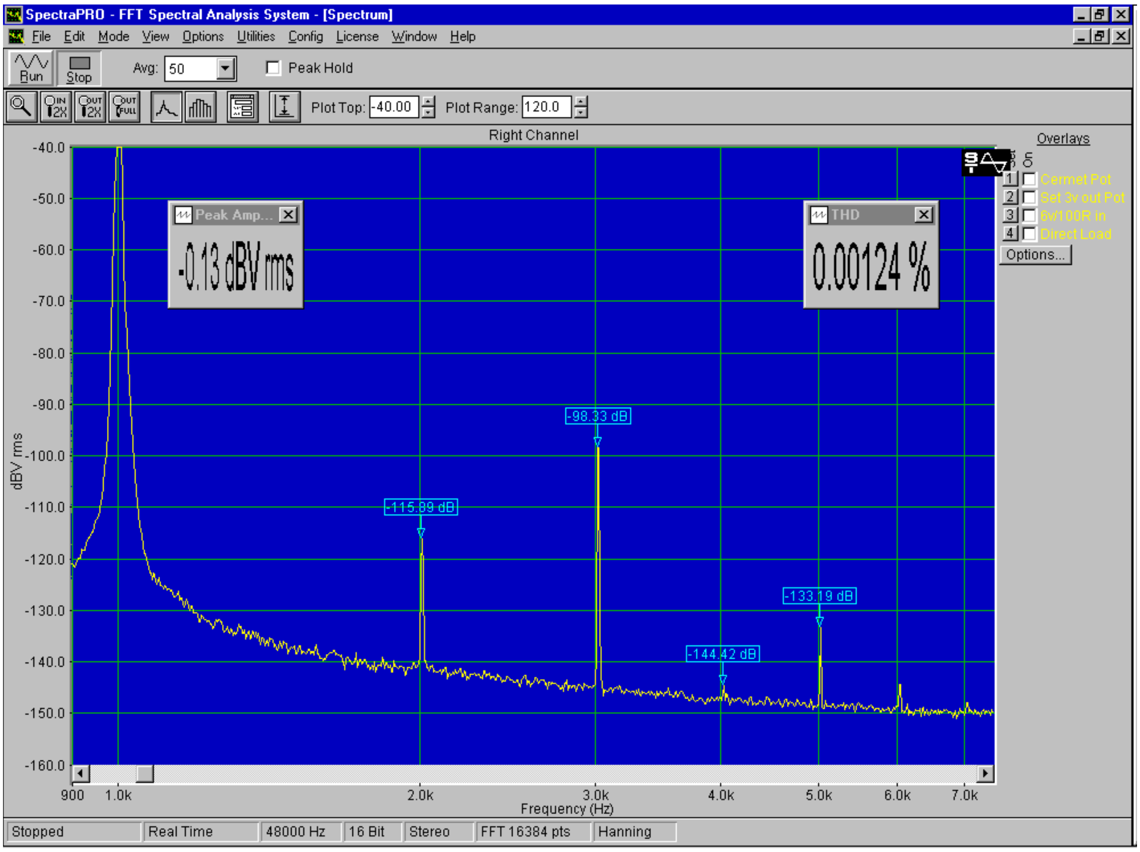
Figure 11) This multi-turn cermet trimmer, set as a 5k6Ω variable resistor and tested with a 6v signal from 1kΩ source impedance, generated this enormous -97dB third harmonic, 0.00138% harmonic distortion.

Tested exactly the same a low cost carbon control produced 0.00129% while a conductive plastic control and 10 turn wirewound generated only 0.00009% and 0.00007%.

Used as a potentiometer.
While the above test reasonably simulated use as a variable resistor, many potentiometers and pre-sets are used as potential dividers or volume controls. To simulate this requirement I connected my 6v test signal to one end terminal, the other end to ground, then set the wipers to measure a 3v output signal. To ascertain the effect of wiper contact linearity, each control was tested twice, once with my notch filter input switched to 'pre-amp' for a negligible 10 µA wiper current, then switched to the 'direct' position, a 13k5 Ω resistance in parallel with 10n2F capacitance, drawing some 225µA through the wiper to ground.

With the 10µA wiper current, the 10T wire wound measured 0.00006%, the carbon and conductive plastic controls 0.00007% . The cermet trimmer third harmonic increased by 16dB to measure 0.00037% distortion. Clearly this increase results mainly from the cermet resistive element, not the wiper contact which was passing only 10µA of current compared with 600µA through the element. Distortion was third harmonic at -109dB, second -120dB.

To determine how increased wiper current might be a factor, I re measured each with the pre-amp switch set to 'direct', for 225µA wiper current. The wire wound and conductive plastic controls changed little, reading 0.00006% and 0.00009%. The low cost carbon control measured 0.00039% distortion, indicating its wiper made reasonable contact, whereas the cermet trimmer measured very badly, at 0.00124% its distortion was dominated by a very high, -98dB third harmonic. **Fig. 12**


SpectraPRO - FFT Spectral Analysis System - [Spectrum]

Avg: 50

☐ Peak Hold

Plot Top: -40.00

Plot Range: 120.0

Right Channel

Peak Amp... -0.13 dBV rms

THD 0.00124 %

Overlays

1 ☐ Cermet Pot

2 ☐ Set 3v out Pot

3 ☐ 6v/100R in

4 ☐ Direct Load

Stopped | Real Time | 48000 Hz | 16 Bit | Stereo | FFT 16384 pts | Hanning

Figure 12) Re-connected as potentiometers to output a 3v test signal drawing 225µA through their wipers, produced a similar distortion pattern.

The cermet control with 0.00124% distortion was worst, the low cost carbon was much better at 0.00039%, the conductive plastic and wirewound measuring just 0.00009% and 0.00005% respectively.

Variable Resistors and Potentiometers - Conclusions.

Clearly to minimise distortion, the lowest possible Ohmic value variable resistors, together with fixed value metal film resistors to make the required value, should be used. Variable resistors, potentiometers and pre-set controls must be subject to the smallest possible through and wiper currents. Particular care must be taken to avoid passing capacitive load currents through the wiper contacts, e.g. in tone controls, which could result in unexpected tone control distortions.

For almost all applications, a conductive plastic control will produce low distortion while avoiding any reactive loading problems which may result when using a wire wound control.

When a cermet type control must be used, it is essential to make certain it is subjected only to small voltage drops with small currents passing through the element and none or very little current is drawn through the wiper.

Conclusions.

This series has shown how using low cost self build equipment and simple test methods, one can easily measure the distortions generated by most components used in modern audio systems as well as complete amplifiers, in the hope many readers will replicate these measurement methods. Gain understanding, especially of capacitor functions and help to eliminate many popular misconceptions. Improving our knowledge base by using real measurements to replace subjective opinion.

End.

References**.**

1) Op-Amp Audio. Walt Jung. Electronic Design, September 1 to December 14, 1988.
http://www.elecdesign.com/content/ 3004, 2800, 1474&1518.html

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3) Capacitor Sounds. C.Bateman. Electronics World, January 2003

4) Capacitor SoundsII. C.Bateman. Electronics World, September 2003.

5) Differential-in 100MHz scope probe. C.Bateman Electronics World, December 2001.

6) Capacitor Sounds. C.Bateman. Electronics World, September 2002.

Technical Support.
Full details of the "Real Time" hardware test method and my original "Capacitor Sounds" low distortion oscillator, buffer amplifier, notch filter/pre-amplifier and DC bias assemblies, complete with parts lists, assembly manuals and full size printed circuit board drawings, as .PDF files arranged for easy viewing of the figures, on screen or hardcopy, are provided in my CD.

This CD includes updated and much expanded re-writes with very many more figures, of my first series 'Capacitor Sounds' articles, supported now by some ninety capacitor distortion measurement plots as well as all six articles from this new "Capacitor SoundsII" series.

Also included are PDF re-writes of my earlier 'Understand Capacitors' series together with articles how to diagnose failed printed board mounted capacitors and essential low cost capacitor measurement methods, more than twenty popular articles.

This final version of my CD, now with 'artwork' label, costs £15 Sterling inclusive post packing.

Upgrade. Readers who purchased an earlier CD, can now upgrade to this version for £5 Sterling, inclusive.

I can still supply sets of three professionally manufactured printed circuit boards, FR4 with legend and solder resist, also four gang potentiometers, as described in my original Capacitor Sounds articles.

One set of boards costs £27.50 but due to weight, post and packing is extra.
Four gang potentiometer if ordered together with PCB's costs £5.00.

Post packing UK and EU	£3.50
Rest of World	£7.50

Send cheques or postal/money orders in Pounds Sterling only to:-
C.Bateman.
'Nimrod'
New Road.
ACLE.
Norfolk.
NR13 3BD.
England.

Box **FFT Software.**

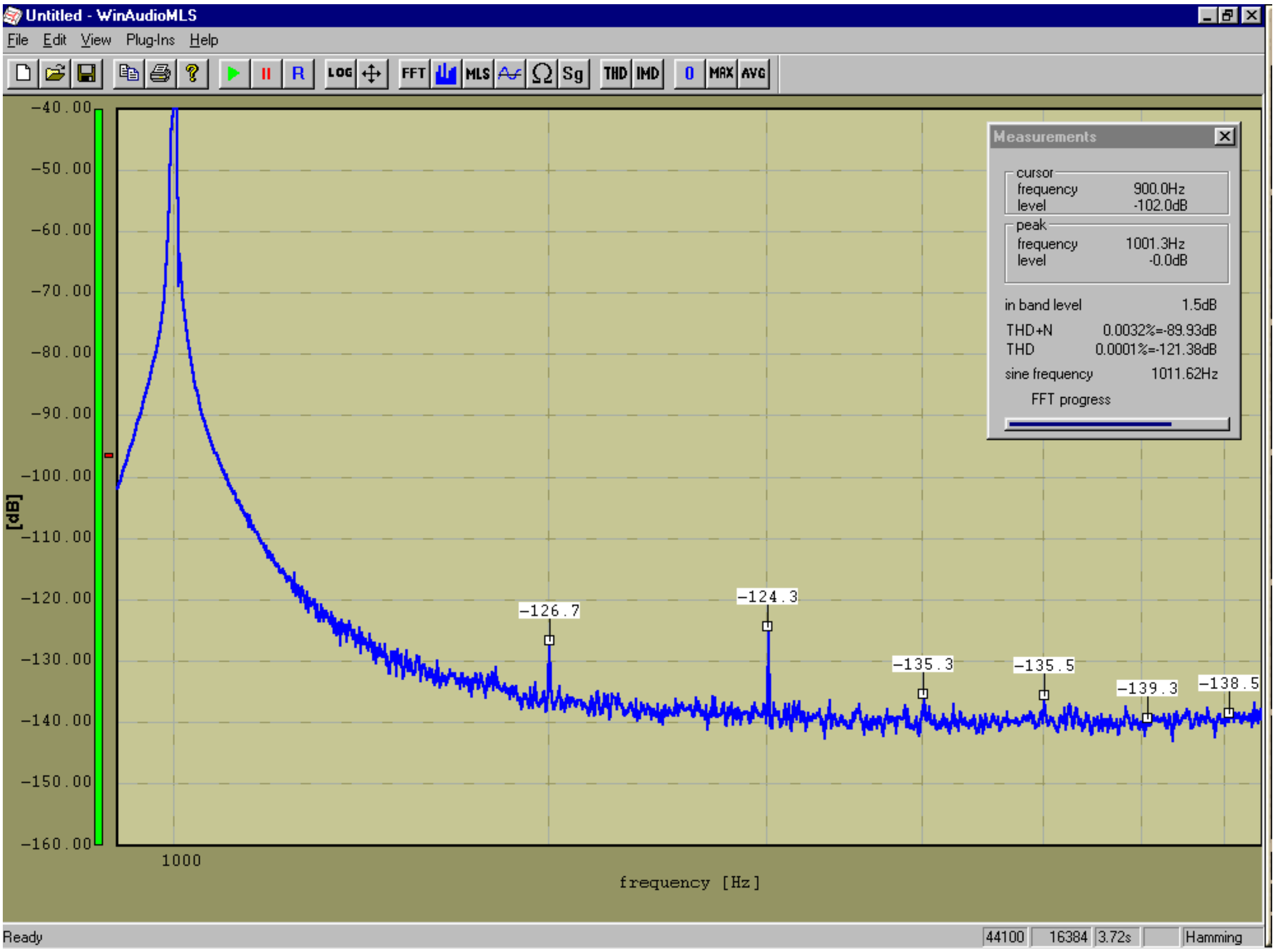
Throughout my Capacitor Sounds series except the first two articles, I used the SpectraPlus232 software for my distortion plots. This software is easy to set up and has served well. However some readers have asked whether lower cost software might be used, since with a full set of options it becomes 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/pre-amplifier 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 cost upgrade options, but I found the base WinAudioMLS Pro version with their THD% option, sufficient for my needs.



cursor
frequency 900.0Hz
level -102.0dB

peak
frequency 1001.3Hz
level -0.0dB

in band level 1.5dB

THD+N 0.0032%=-89.93dB
THD 0.0001%=-121.38dB

sine frequency 1011.62Hz

44100 | 16384 | 3.72s | Hamming

Contact

WinAudioMLS Pro	http://www.dr-jordan-design.de
SpectraPlus232	http://www.soundtechnology.com