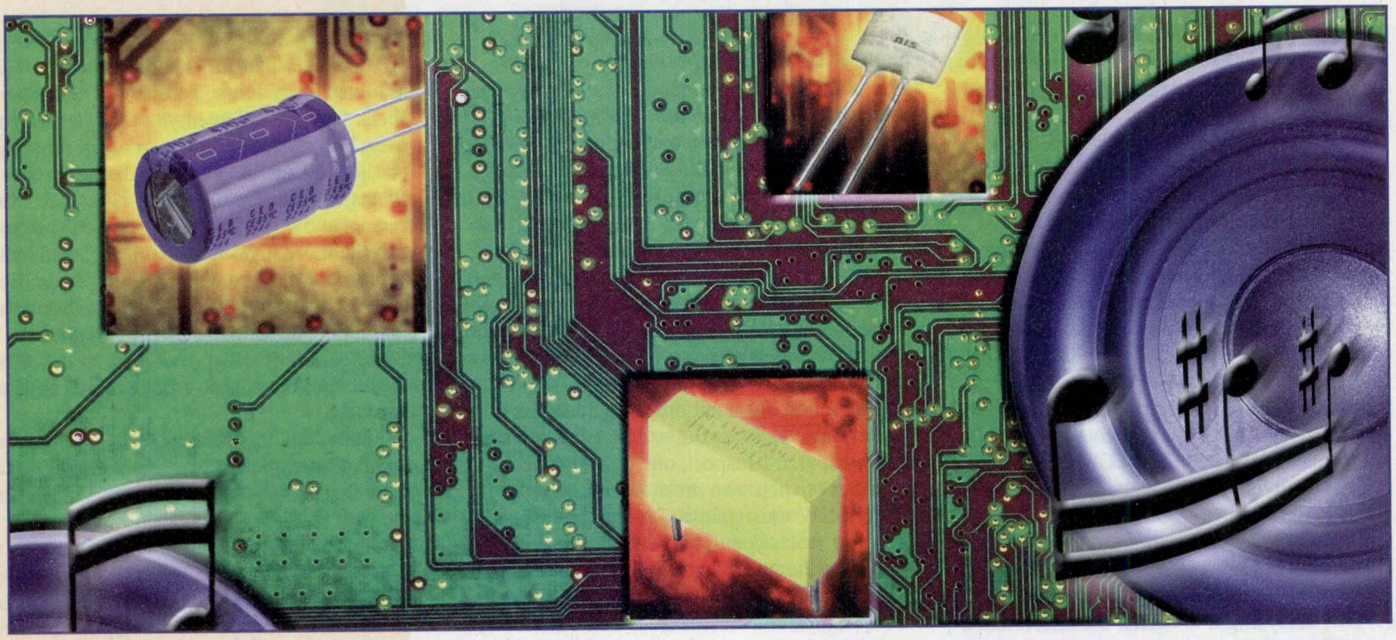


Capacitor sound 5

- 1µF choice - Electrolytic or Film?

Many capacitors introduce distortions onto a pure sinewave test signal. In some instances distortion results from the unfavourable loading which the capacitor imposes onto its valve or semiconductor driver, though more often, the capacitor generates the distortion within itself. Cyril Bateman continues his capacitive deliberations

For too long capacitor generated distortions have been the subject of much speculation and opinion. Capacitors are not categorised for distortion in manufacture, so a distorting capacitor would not be accepted as reject by its maker, but this can now be measured. Using my easily replicated test method, audio enthusiasts can select capacitors when upgrading their equipment and designers can select capacitors for each circuit requirement.

For 100nF capacitance we find the lowest distortions are generated by choosing either C0G multilayer ceramic, metallised film Polyphenylene Sulphide (PPS) or double metallised film electrodes with Polypropylene (PP) film.[1]

At 1µF, C0G ceramic types are not generally available, reducing our low distortion choice to the above two film types or a selected metallised Polyethylene Terephthalate (PET). To guarantee low distortion we found that metallised PET types should be distortion tested and used with no bias or with modest DC bias voltages. The PPS and PP capacitor types produce exceptionally low distortions but are larger and more expensive. **Fig. 1.**

To minimise costs at 1µF and above, many designers elect to use low cost polar aluminium electrolytic capacitors. We now explore this option.

Electrolytic capacitors

At room temperature and 1kHz, a typical 1µF 63 volt polar electrolytic capacitor can sustain some 30mA AC current. By measuring its distortion at 1kHz we obtain a direct comparison of polar electrolytic distortions with the film capacitors of my last article.

There are a lot of myths surrounding the aluminium electrolytic capacitor. As with other capacitor types, much has been written about the sound distortions they cause. However of all capacitor types, electrolytics are the most complex and the least well understood. Many myths, specific to electrolytics have emerged, based more on speculation than on fact.

a) Aluminium electrolytic capacitor dielectric has extremely high 'k'.

b) Electrolytic capacitor distortion is mostly third harmonic.

c) For minimum distortion, electrolytic capacitors should be biased to half rated voltage.

d) Back to back polarised capacitors, biased by the supply rail, minimise distortion.

e) High ESR Electrolytics degrade sound quality, low ESR is always best.

f) Electrolytics are highly inductive at audio frequencies.

g) High voltage electrolytics sound the best.

A working knowledge of electrolytic construction combined with careful distortion measurements, leads to somewhat different conclusions.

Polar Aluminium electrolytic construction

To begin to understand an electrolytic capacitor we must explore how it differs from other capacitor types including Tantalum.

Every traditional aluminium electrolytic capacitor actually comprises two polar capacitors in series, connected back to back.[2]

The dielectric for the wanted capacitance is a thin aluminium oxide coating that intimately covers the 'anode' foil. The metal core of this anode foil, acts as one capacitor electrode. The second electrode is provided by a conductive electrolyte surrounding the anode foil.

A 'cathode' foil is used to make electrical contact between this electrolyte and the lead-out wire. This cathode foil is covered by a much thinner, naturally occurring aluminium oxide, the dielectric for our second capacitor. Electrically similar to oxide produced using a 1 to 1.5 volt 'forming' voltage, capacitance of this cathode is many times that of the anode.

The effective surface area of the anode and cathode foils is much enlarged by mechanical and electro-chemical etching. Low voltage capacitor foil areas may be increased perhaps one hundred times larger than the foils superficial or visible area. In this process a myriad of minute tunnels are created in the aluminium foils, which become sponge like and porous.[2]

An extremely thin layer of dielectric, aluminium oxide with a 'k' of eight,[3] is electro-chemically 'formed' or grown on the surface of the anode foil. Depending on the desired end use, a general-purpose capacitor may be formed at 1.25 times, a long life capacitor to double its rated voltage.

The thickness of this dielectric oxide is self limiting, being controlled by the voltage used in the forming process. As thickness approaches 14 Angstrom for each forming volt applied, oxide growth slows down and almost ceases.[2]

Because aluminium oxide takes up more space than the aluminium which is converted in the 'forming' process, different etching methods are used according to the intended forming voltage. For the lowest voltage capacitors, the most minute tunnels are etched into both foils.

Formed to 50 volts, oxide growth would completely fill these minute tunnels. The etching process is adapted to produce somewhat larger tunnels, which can be formed - perhaps to 100 volts. For higher voltages, progressively larger tunnels must be etched.[2] Becromal (one supplier of capacitor foils) lists some fourteen different grades of etched anode and a bigger selection of cathode foils.

As capacitor rated voltage increases, less conductive electrolytes and thicker separator tissues must be used. To reduce element size and cost, thinner, lower gain cathode foils may be chosen.

These changes combine to produce a near optimum quality, low tanδ, low distorting capacitor when rated for 40 to 63 volt working, with notably poorer qualities above 100 volt and at the lowest voltage ratings.

Assembly

The required length of anode and a slightly longer length of cathode foil are wound together, cathode foil out onto a small rotating spindle. To minimise mechanical damage to the extremely thin dielectric oxide coating, the foils are interwound together with soft insulating separators. Thin 'Kraft' or 'Rag' tissue paper the most common.

Aluminium has an electro-chemical potential of +1.66v. To avoid corrosion, no metal other than aluminium may be used inside the capacitor case. The external lead wires, copper at -0.337V or steel at +0.44V, must be excluded from all contact with electrolyte.

Prior to winding the element, thin aluminium connecting 'tabs' are mechanically and electrically connected to both foils. The most common method is 'eyeletting', when a shaped needle pierces both the connecting tab and its foil. Small 'ears' of tab material are turned over and well flattened down, effectively riveting both parts together. **Fig. 2.**

Cold pressure welds, seen in this photo connecting the aluminium 'tabs' to the outer tag rivets, provide the most reliable, low and linear resistance, connection of aluminium to aluminium. By applying pressure over small areas, metal is forced to flow between the two items, which become permanently welded together. This method is often used to replace 'eyeletting' in the best constructed capacitors. The completed winding is vacuum impregnated with electrolyte, which becomes absorbed into both foils and separator papers. Producing a low resistance connection between the anode and cathode foil capacitances.

Bi-polar Aluminium electrolytic capacitor construction

A bi-polar electrolytic is made in exactly the same way as a polar capacitor, with one significant difference. In place of the cathode foil, we use a second anode foil. We still have two polar capacitances in series, back to back. Both now the same value and working voltage. This bi-polar capacitor will measure half the capacitance of either anode foil - to make the required value, two anode foils, each double the desired capacitance, are used.

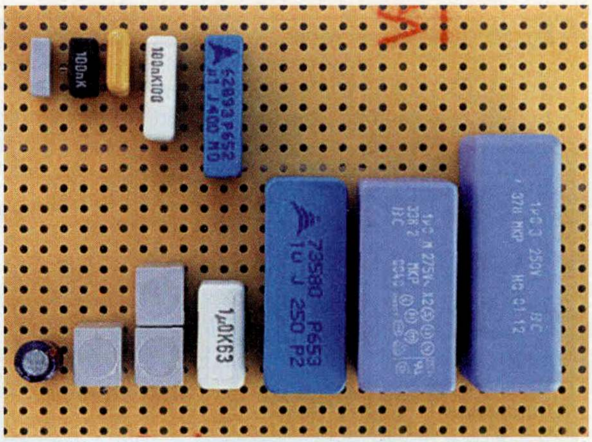


Figure 1: Bottom row left 1μF, the best electrolytic, the Bi-polar, was outperformed by the 470 type 63v metallised PET capacitor. The SMR capacitor is fourth and the B32653 fifth from left. Top row 0.1μF, the 50v and 100v SMR capacitors second and fourth, the B32652 fifth from left.

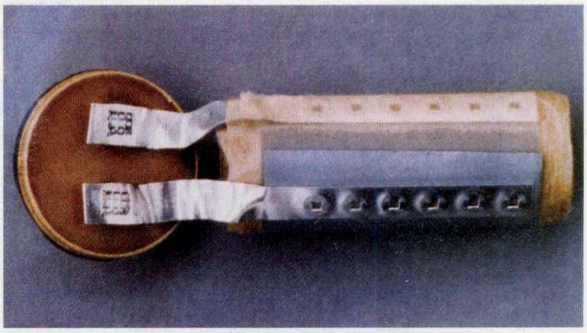


Figure 2: The 'eyeletting' type connections most often used to connect aluminium lead out tabs to the centres of both cathode and anode foils. For clarity the outermost anode and cathode foil turns have been removed. The cold pressure welds connecting these tabs to the tag rivets can be seen.

Aluminium electrolytic capacitor designers are accustomed to mixing and matching their available materials, to suit the capacitor's end application. So it should not surprise that some designs are semi bi-polar, i.e. they are made using a lower voltage deliberately 'formed' anode foil as cathode.

Equivalent circuit

Using this constructional background, we can deduce an equivalent circuit for a polar aluminium electrolytic capacitor. **Fig. 3**

Dielectric Oxide

Aluminium oxide has a 'k' of eight,[3] similar to that of C0G ceramic or impregnated paper capacitors. It is rather higher than PET, which at 3.3, has the highest 'k' of commonly used films. A low value compared to the 'k' of several thousand, found in X7R and Z5U ceramics.[4]

While the impregnant used in paper capacitors is an insulator and acts as the dielectric, the electrolyte used in electrolytic capacitors is a conductor so cannot be a dielectric. This electrolyte is used to provide a low resistance connection between the two capacitors. More significant than 'k' value is dielectric thickness. Large capacitance values are possible because the dielectric of a 50 volt aluminium electrolytic capacitor is some 100 times thinner than that used in a metallised film capacitor. Ref.2 As a result, electrolytic capacitors are sensitive to dielectric absorption effects.

The dielectric oxide film has a measurable voltage coefficient of capacitance. When DC biased, the measured capacitance of a 1μF 63 volt capacitor increased 0.15% at -0.5 volt. Initially decreasing 0.05% at +0.5 volt, capacitance then increased to +0.16% at +10 volt.

Voltage effects

We explore these voltage effects by measuring the distortion produced by a 1μF 63 volt polar electrolytic capacitor, subject to different AC test voltages. Commencing with 0.1 volt, capacitor distortion was measured at 0.1 volt increments to 1 volt. Initially we test with no bias, then with various DC bias voltages. Remember these voltages are those measured across the capacitor terminals and not the generator set voltage. Small test voltages reduce measurement dynamic range. Distortion of the test capacitor will be compared with those produced by a near perfect film capacitor, tested the same as reference. All tests use my DC bias buffer and two frequencies, 100Hz/1kHz to observe intermodulation.

Electrolytic capacitor behaviour varies with temperature. To minimise the affect of temperature changes, all reported tests were performed at constant room temperature. Unless otherwise stated, all voltages are RMS, measured using a DMM.

Without DC bias

Notably larger distortions were produced by this electrolytic than the film capacitor, even with a test signal as small as 0.1 volt, across the capacitor.

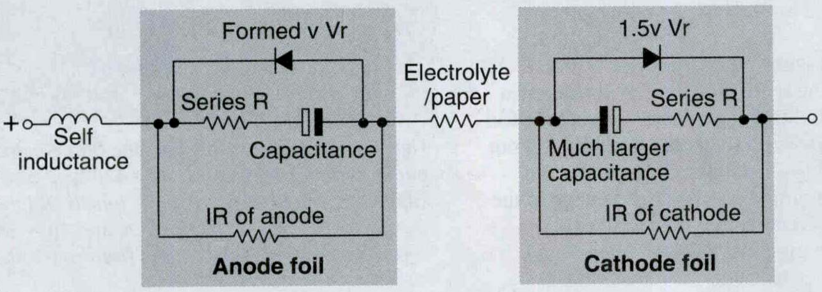
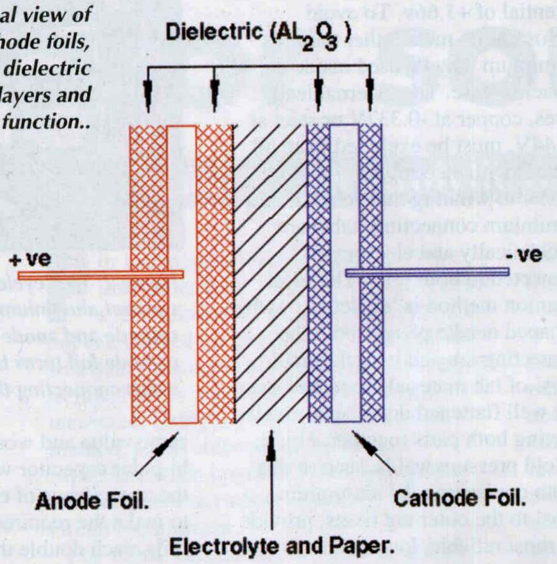


***Figure 3:** This simplified equivalent schematic illustrates how a polar electrolytic capacitor behaves. For clarity, components needed to account for dielectric absorption, are omitted.*

Figure 3a: Sectional view of anode and cathode foils, showing their dielectric oxide layers and electrolyte/paper function..



Capacitance of an electrolytic

The high capacitances available in an electrolytic are the result of the effective surface area of the etched and 'formed' anode foil combined with its exceptionally thin dielectric. This effective area is many times larger than the apparent or visible surface area. The extremely thin, electro-chemically 'formed' dielectric oxide film has a modest 'k' value of eight.[3, 6]

$$\text{capacitance} = \frac{\text{electrode area x 'k' x } 0.0885}{\text{dielectric thickness. in pF/cm.}}$$

This increase in area or 'gain', is greatest for very low voltage rated capacitors, reducing with increasing voltage.

The cathode foil is covered by the oxide film which coats all aluminium surfaces once exposed to air. Some 20 Angstroms thick, it is equivalent to a 1.5 volt electro-chemically formed oxide. Much thinner than that 'formed' on the anode foil, this cathode foil oxide creates our second capacitor. It has a small usable voltage and much larger capacitance than the anode foil.[2] **Fig.3**

This naturally occurring, extremely thin, low quality cathode foil oxide, has increased voltage coefficient than the anode foil. This cathode capacitor allows an aluminium electrolytic to operate on small AC voltages, without polarisation. Correctly polarised the 'formed' aluminium oxide dielectric on the anode foil is an excellent insulator. When reverse polarised it becomes a low resistance as though a diode has been connected in parallel with a good capacitor.

In similar fashion, the naturally occurring cathode oxide film behaves like a capacitor in parallel with a diode. This diode's polarity is in opposition with that of the anode. Because the cathode oxide is thinner, it produces a more leaky diode. The capacitor should never be reverse polarised. Any DC polarisation voltage must be correctly applied with the positive voltage to the capacitor's anode terminal.

Tested with a 0.3 volt signal, distortion of this typical 1μF 63 volt polar electrolytic capacitor, dominated by second harmonic, measured 0.00115% - almost three times greater than the reference capacitor. **Fig. 4.**

When the peak of the AC voltage applied across this unbiased polar capacitor exceeds some 0.5 volt, the cathode foil's voltage dependant effects increase. Tested at 0.4 volt RMS, both harmonics increase relative to the small change in test signal. Second harmonic voltage has almost doubled compared to the 0.3 volt test. Distortion is now four times greater than our reference capacitor. **Fig. 5.**

When the peak voltage across this capacitor exceeds some 0.8 volt, intermodulation distortions appear. Tested at 0.7 volt RMS, second and third harmonic levels have increased much faster than the test voltage. Distortion, dominated by the second harmonic, is now ten times greater than our reference capacitor. **Fig. 6.**

When subject to a 1 volt sinewave, the cathode capacitance varies even more and its diode may conduct on signal peaks. Much larger increases of distortion result, now 22.4 times greater than measured on the reference capacitor. **Fig. 7**

The above voltages apply to this test capacitor. With other combinations of anode voltage and cathode foil, these voltages will vary. With larger capacitance and lower voltage capacitors the same effects are observed, but frequently at smaller voltages.

Regardless of capacitance, working voltage or manufacturer, the second harmonic was the largest distortion component for every unbiased polar electrolytic capacitor measured.

Myth

In the past various writers have stated that electrolytic distortion commences when a capacitor is subject to 1.4 volts peak, or 1 volt RMS sinewave. Doug Self once described this 1.4 volts as the voltage "which appears to be when depolarisation occurs in practise. Naturally distortion results as the capacitor dielectric film starts to come undone." [5]

On both counts this is wrong. As we have seen, significant distortions occur at much lower voltages.

While the thin aluminium oxide film

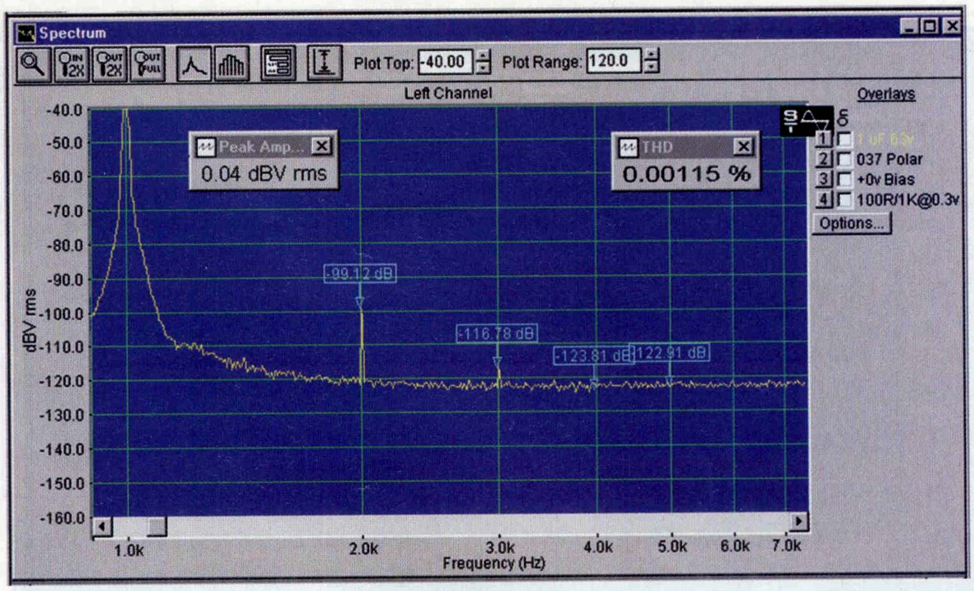

Plot Top: -40.00
Plot Range: 120.0
Peak Amp... 0.04 dBV rms
THD 0.00115 %

Figure 4: Distortions measured on our 1μF 63 volt polar capacitor, using a 0.3 volt test signal without DC bias. Note how the large second harmonic component dominates all others.

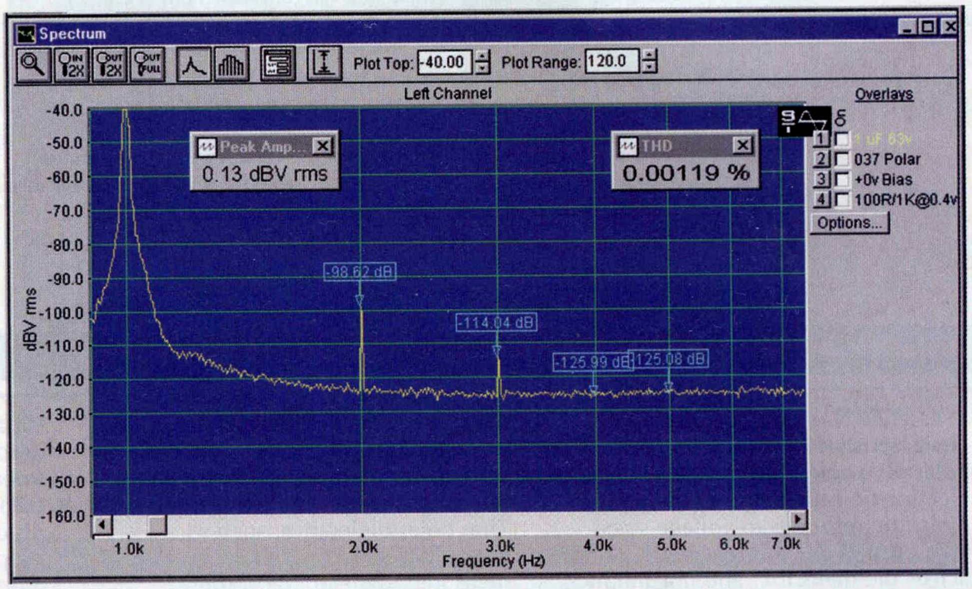

Plot Top: -40.00
Plot Range: 120.0
Peak Amp... 0.13 dBV rms
THD 0.00119 %

Figure 5: Both second and third harmonics have increased relative to the 0.4 volt test signal. The second much more than the third. Intermodulation components remain buried in the noise floor.

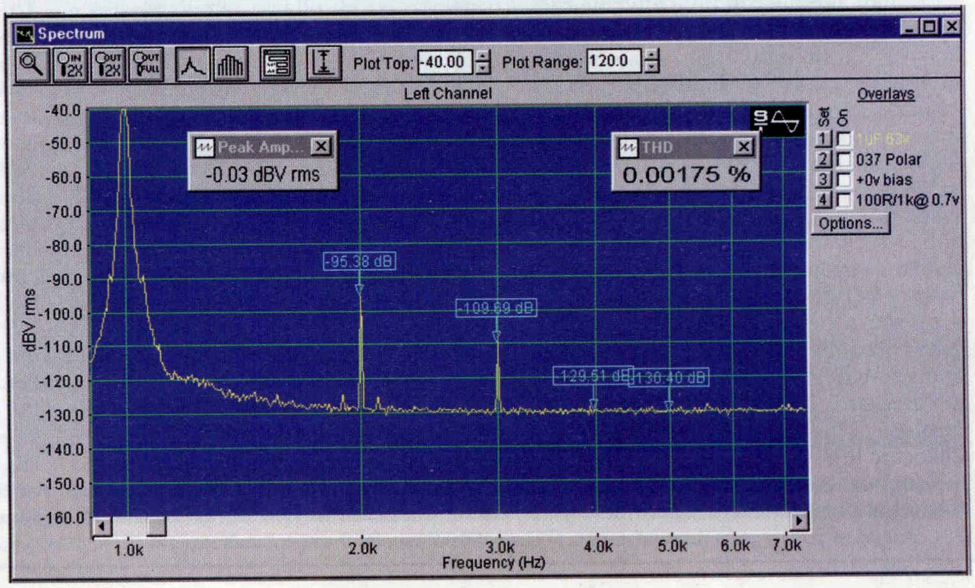
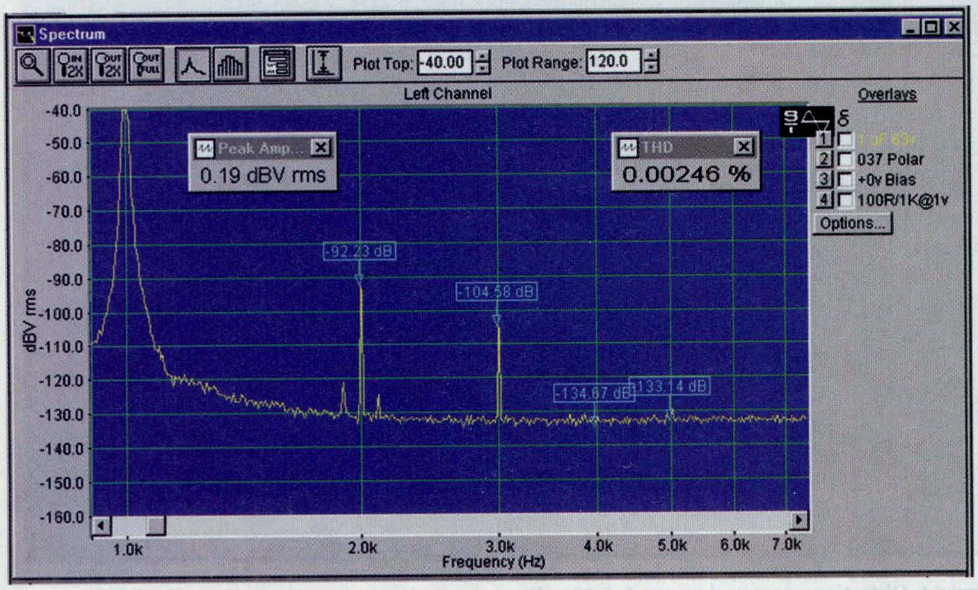

Plot Top: -40.00
Plot Range: 120.0
Peak Amp... -0.03 dBV rms
THD 0.00175 %

***Figure 6:** At 0.7 volt, with the third harmonic some -110dB below the test signal, intermodulation products can be seen either side of the second harmonic.*



Plot Top: -40.00

Plot Range: 120.0

Peak Amp... 0.19 dBV rms

THD 0.00246 %

Figure 7: With a 1 volt test signal and no bias, the capacitor is producing 22.4 times more distortion than the film reference capacitor. Second and third harmonic components have increased out of all proportion to the test signal.

is easily mechanically damaged, like anodised aluminium, electro-chemically it is extremely robust. It requires substantial time and/or energy, to revert the aluminium oxide structure. Capacitor specifications permit short-term voltage reversals up to 1.5 volts, when the capacitor must remain undamaged.

If severely abused by significant reverse voltage or excessive ripple current, a conventional aluminium electrolytic may explode. Not because the aluminium oxide film has deteriorated, but simply because these conditions result in large internal currents. Hydrolysis releases gases from the electrolyte and internal pressure increases until the capacitor case breaks.

To help interpret the above results, I converted the 2nd and 3rd harmonic distortion levels into μV. Plotted against test voltage, both harmonic voltages clearly increase ever more rapidly with increase in test voltage. **Fig. 8**

With DC bias

Looking once more at our equivalent circuit we see the anode and cathode foil leakage resistances with the electrolyte, create a DC potential divider chain. Application of a small positive DC bias with no AC signal, raises the electrolyte voltage above the negative terminal, see Fig. 3.

However subject to an AC test signal and DC bias, the anode and cathode capacitance values with their respective diodes, modify the electrolyte's potential. Tested with AC only, the electrolyte potential becomes slightly negative with respect to the negative terminal, resulting in an increase of second harmonic distortion. Subject to a small DC bias and an AC signal, the electrolyte potential increases. It can become zero or even slightly positive with respect to the negative terminal, reducing second harmonic distortion.

Dielectric Absorption

In essence two major dielectric characteristics exist - polar and non-polar. By polar, I am not referring to an electrolytic capacitor, but the way a dielectric responds to voltage stress. This stress is the voltage gradient across the dielectric, and not simply the applied voltage. It is stress in volts per micron, which matters.

Vacuum and air, are little affected by voltage stress. Solid dielectrics which behave in a similar fashion are termed 'non-polar'. Most solid dielectrics and insulators are affected to some extent, increasing roughly in line with their dielectric constant or 'k' value. This 'k' value is the increase in capacitance when the dielectric is used to displace air.

When a dielectric is subject to voltage stress, electrons are attracted towards the positive electrode. The electron spin orbits become distorted creating stress and a so-called 'space charge' within the dielectric. This stress produces a heat rise in the dielectric, resulting in dielectric loss.

Non-polar dielectrics exhibit small losses but polar dielectrics are much more lossy. Having been charged to a voltage, it takes longer for the electron spin orbits in a polar dielectric to return to their original uncharged state. Thin polar dielectrics, such as aluminium oxide, produce large, easily measured 'dielectric absorption' effects.

Dielectric behaviour with voltage depends on the voltage gradient in volts/micron and the characteristics of the dielectric. Its effects are more readily apparent at low voltages with thin dielectric. The dielectric used in low voltage electrolytics is exceptionally thin. Consequently we find increased effects from dielectric absorption when measuring these types.

Dielectric absorption is measured by fully charging the capacitor for several minutes, followed by a rapid discharge into a low value resistor for a few seconds. The capacitor is then left to rest for some time after which any 'recovered' voltage is measured. The ratio of recovered voltage to charge voltage, is called dielectric absorption.

So how might dielectric absorption affect the distortion produced by a capacitor? Many fanciful, even lurid descriptions can found, describing smearing, time delays and signal compression. My capacitance and distortion measurements do not support these claims. The main difference I found which clearly does relate to dielectric absorption, is the magnitude of the second harmonic. This increases with applied voltage, especially so with electrolytic capacitors.

My measurements indicate it is the level of third and odd harmonics generated by the capacitor that determines intermodulation products. These harmonics are little affected by DC bias on the capacitor. No doubt intermodulation distortions would contribute to a muddled or smeared background sound.

Third harmonic distortion depends on the peak voltage across the capacitor. For a given signal level, voltage across the capacitor will be greatest at the lowest frequencies. A low frequency, large signal peak, can trigger intermodulation distortions, which then affects higher frequencies.

These changes in electrolyte potential are easily confirmed by simulation using our equivalent circuit. This positive shift has a beneficial reduction on the AC signal non-linearity produced by the capacitor, measurable as a substantial reduction in second harmonic distortion. With optimum DC bias, the second harmonic may become smaller in amplitude than the third harmonic. Tested at 1 volt with 6 volt DC bias, distortion was reduced from 22.4 to 6.5 times greater than the reference capacitor. **Fig. 9**

Myth disproved

Only when a polar electrolytic capacitor is biased near its optimum voltage does second harmonic reduce, third harmonic may then dominate. Optimum bias varies with the applied

Technical Support

Interested readers are free to build a system for personal use or educational use in schools and colleges. Commercial users and replicators should first contact the author.

A professionally produced set of three FR4 printed circuit boards, with solder resist and legends, for the 1kHz signal generator, the output buffer amplifier/notch filter/pre-amplifier and the DC bias buffer network, comprising a 'with DC bias, single frequency, distortion test system'. Complete with component parts lists and assembly notes, the set of three boards costs £32.50.

Post/packing to UK address £2.50. Post/packing to EU address £3.50, rest of world £5.50.

As a service to Non-UK readers, but only if ordered together with the above PCB's, I can now supply one four gang potentiometer with each set of boards, re-tinned and tested, for an additional £5.00 inclusive of postage.

Falcon Electronics (EW September) has these potentiometers in stock.

Postal Orders or Cheques, for pounds sterling only, to C. Bateman. 'Nimrod' New Road. ACLE. Norfolk, NR13 3BD, England.

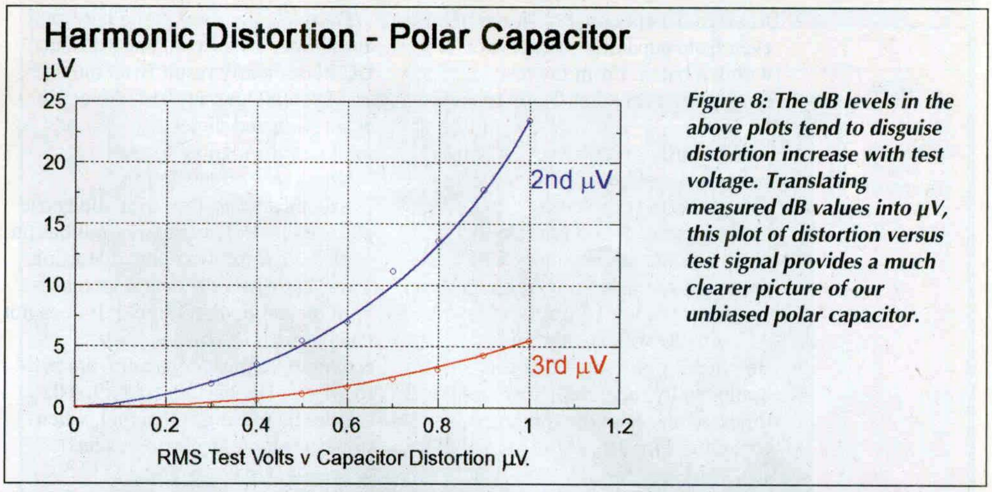


Figure 8: The dB levels in the above plots tend to disguise distortion increase with test voltage. Translating measured dB values into µV, this plot of distortion versus test signal provides a much clearer picture of our unbiased polar capacitor.

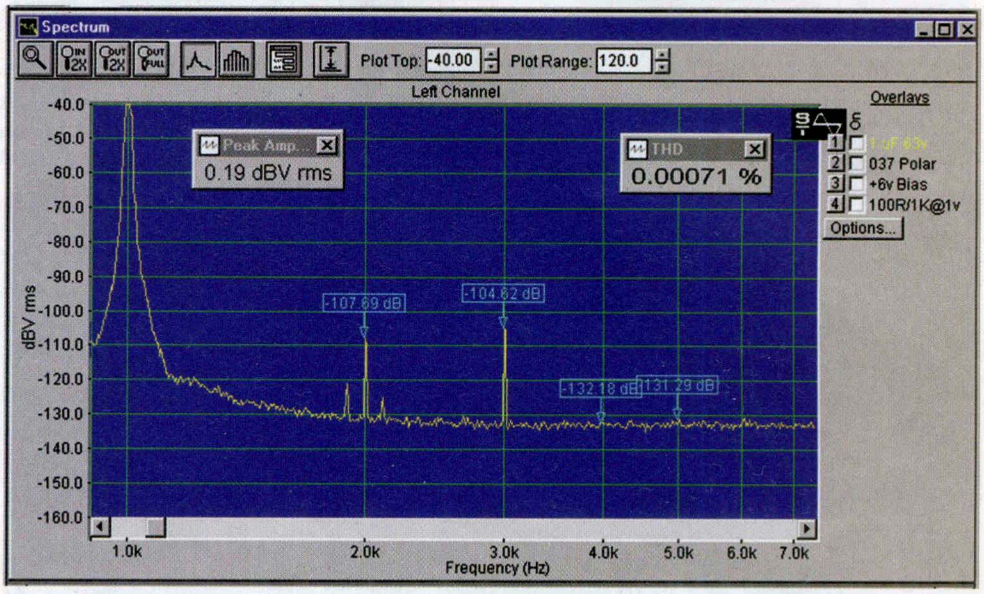

Plot Top: -40.00
Plot Range: 120.0
Peak Amp... 0.19 dBV rms
THD 0.00071 %

Figure 9: Measured as for figure 7 but using a 6 volt DC bias. Notice how the third harmonic and the intermodulation products remain constant despite the dramatic reduction in second harmonic level with this DC bias.

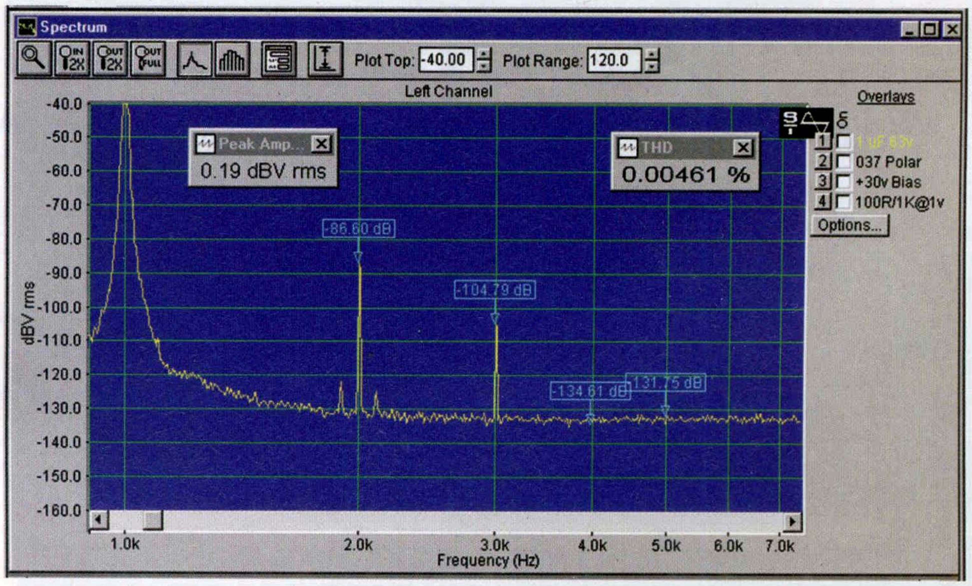

Plot Top: -40.00
Plot Range: 120.0
Peak Amp... 0.19 dBV rms
THD 0.00461 %

Figure 10: Measured as for figure 7 but with 30 volt DC bias. The capacitor is polarised to one half its rated voltage, the 'myth' value. Second harmonic has increased dramatically and distortion doubled compared to no bias figure 7. Intermodulation products and third harmonic are unchanged, from no bias to 30 volt.

AC signal, capacitor construction and even from capacitor to capacitor within a batch. From my tests, it ranged from less than 1 volt to some 12 volt.

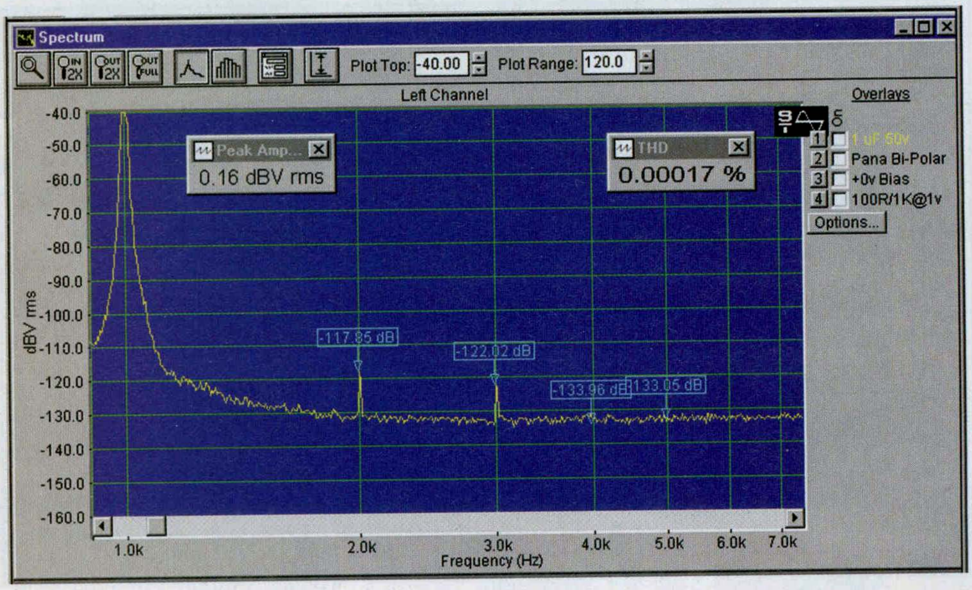
With further increase of DC bias voltage, the effects of dielectric absorption outweigh this improvement. Second harmonic distortion increases rapidly with bias voltage. I re-measured this electrolytic and the reference capacitor at 1 volt AC with 30 volt DC bias, its 'mythical' optimum. Distortions dramatically increased, now almost 42 times greater than the reference capacitor. **Fig. 10.**

These changes in second harmonic amplitude, tested with and without DC bias, clearly result from the AC and DC voltages applied, dielectric absorption and dielectric thickness/formation voltage.

Non-linear effects in the interconnections, the oxide dielectric and the electrolyte/paper combination contribute third harmonic distortion. Third harmonic distortion increases with the applied AC signal. It does not change with DC bias voltage, remaining almost constant from zero to 30 volt DC bias. **Figs. 7, 9, 10.**

With increasing AC signal, when third harmonic distortion exceeds some 0.0003% of the test signal, intermodulation distortions become visible above the measurement noise floor. Any increase in AC signal results in much increased intermodulation and harmonic distortions.

Typically the maximum signal voltage to avoid intermodulation distortion with this 1μF polar capacitor is around 0.5 to 0.6 volt. However, even at these voltages it still produces substantial harmonic distortion. **Figs. 5 and 6.**


Spectrum

Plot Top: -40.00 Plot Range: 120.0

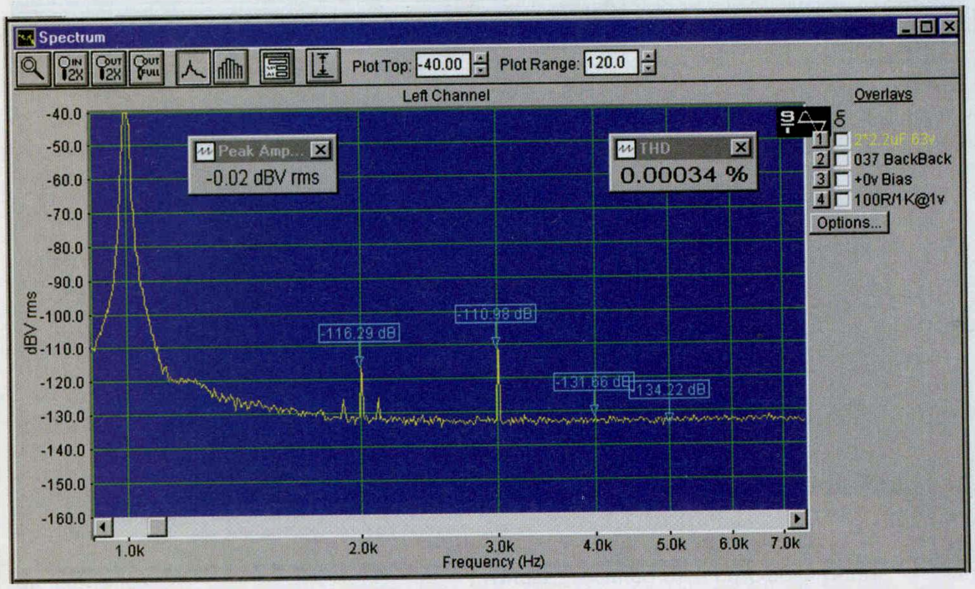
Left Channel

Peak Amp... 0.16 dBV rms

THD 0.00017 %

Overlays
1 ☐ 1 uF 50v
2 ☐ Pana Bi-Polar
3 ☐ +0v Bias
4 ☐ 100R/1K@1v
Options...

Figure 11: The bi-polar electrolytic of figure 1, measured unbiased as for figure 7. The bi-polar shows minuscule harmonic distortions and freedom from intermodulation products, compared to the polar electrolytic. Why do designers use polar electrolytic capacitors in the signal path of an amplifier?


Spectrum

Plot Top: -40.00 Plot Range: 120.0

Left Channel

Peak Amp... -0.02 dBV rms

THD 0.00034 %

Overlays
1 ☐ 2*2.2uF 63v
2 ☐ 037 BackBack
3 ☐ +0v Bias
4 ☐ 100R/1K@1v
Options...

Figure 12: Two 2.2μF 63 volt polar capacitors connected back to back and measured unbiased as figure 11, produce less distortion than the polar capacitor. However with intermodulation products and double the distortion of the bi-polar capacitor, why use two polar capacitors, when one bi-polar is clearly better?

Bi-polar capacitor voltage effects

This construction provides two near identical anode foil capacitances, each subject to half the applied AC signal. Having no low quality cathode foil capacitance, it is freed from its non-linear effects so produces negligible distortion when unbiased. Distortion at 0.00017% is ten times smaller than the single polar electrolytic and just 50% greater than our reference capacitor. **Fig. 11.**

A DC bias voltage unbalances a bi-polar capacitor, resulting in increased second harmonic distortion. With 6 volt DC bias, second harmonic increased to -107.5dB and distortion measured 0.00044%. Little more than half the polar capacitor's distortion with this bias.

Subjected to 30 volt DC bias and a 1 volt test signal, second harmonic increased to -93dB. Third and higher harmonics are unchanged. Distortion at 0.00225% is less than half that of the 1μF polar capacitor and remains free from visible intermodulation.

Two Polar capacitors back to back

Using two polar capacitors each of 2.2μF, connected in series and back to back, produces a chain of four capacitors, with a nominal 1μF capacitance.

With no bias voltage, each polar capacitor sees half the AC voltage. Second harmonic is much reduced and distortion measured 0.00034%. While substantially less than for the polar electrolytic, distortion is double that measured on the Bi-polar capacitor. **Fig. 12.**

With 6 volt DC bias, distortion of our 1μF polar capacitor reduced to 0.00071%, but more than 60% greater distortion than measured on the Bi-polar.

With 6 volt DC bias, second harmonic distortion of the back to back pair increased 20dB becoming dominant and distortion increased fivefold to 0.00169%. **Fig. 13**

At 1 volt AC, regardless of bias

voltage, the single polar capacitor and the back to back pair both produced visible intermodulation.

With 30 volt DC bias, second harmonic distortion for both the single polar capacitor and the back to back pair measured -86dB. Both styles produced intermodulation and similar harmonic distortions, measuring 0.00461% and 0.00472% respectively. More than double that of the bi-polar. **Fig. 14.**

In every distortion test, the bi-polar capacitor produced much lower distortions than measured on similar value and voltage polar capacitors.

Metallised film/electrolytic comparisons

To measure distortions produced by the best film capacitors in my earlier articles, I needed to use a 4 volt AC test signal. I then found several 'bad' capacitors measuring higher than normal distortion.

This 4 volt test signal is much too large when testing electrolytic capacitors. Measured using 12 volt DC bias and a 2 volt test signal, all polar electrolytics produced very high levels of distortion.

Reducing our test signal to 1 volt RMS to permit tests with and without DC bias voltage, which capacitor produces less distortion. A good electrolytic or a poor metallised PET capacitor? Regardless of bias, all polar electrolytic capacitors I measured at 1 volt generated significant levels of intermodulation distortion. The 1μF Bi-polar types were intermodulation free at 1 volt with no bias and to 30 volt DC bias. Measuring a 'known' 1μF metallised PET at 1 volt with no bias and to 30 volt DC bias, I found no visible intermodulation distortions. With 30 volt DC bias, second harmonic distortion was -100dB, distortion was 0.00089%.

The 1μF bi-polar electrolytic, tested at 1 volt and with 12 volt DC bias, measured almost identical distortions, which increased as bias increased. With 30 volt DC bias, second harmonic was -93dB and distortion measured 0.00225%, some 2.5 times worse than the PET. From these 1 volt tests the best 1μF electrolytic, the bi-polar type, was clearly beaten by the metallised PET.

Much better film capacitors were listed in my last article but at 1μF, a metallised PET capacitor provides the economic choice. For the lowest possible distortion, especially with increased signal drive or DC bias, the better quality film capacitor styles as shown in figure 1 and recommended in my last article, should be used. ■

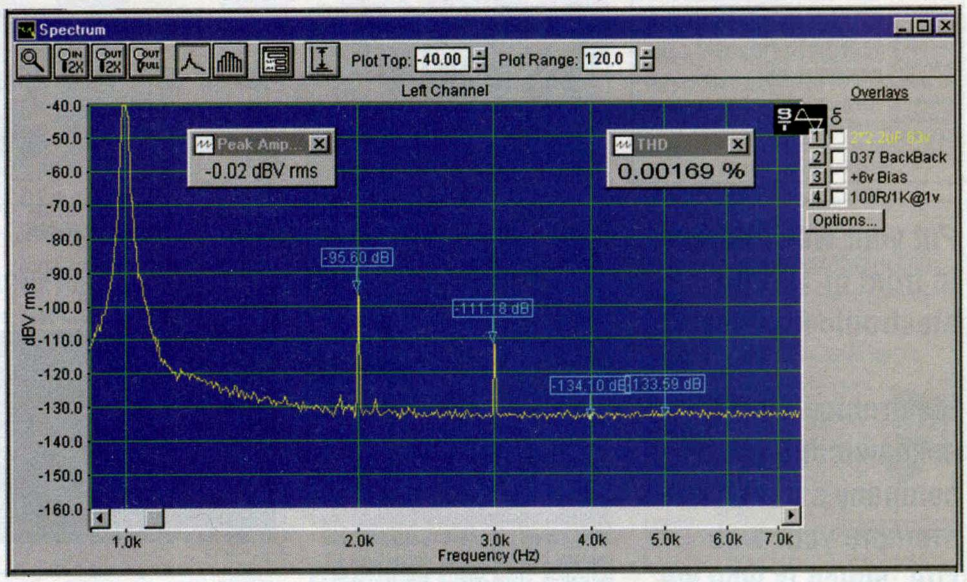

Plot Top: -40.00
Plot Range: 120.0
Peak Amp... -0.02 dBV rms
THD 0.00169 %

Figure 13: Measured exactly as figure 9 with 6 volt DC bias, the back to back connection produces more distortion than our single polar capacitor. The bi-polar type is much better than both. With 6 volt DC bias it measured just 0.00044% distortion and no visible intermodulation products.

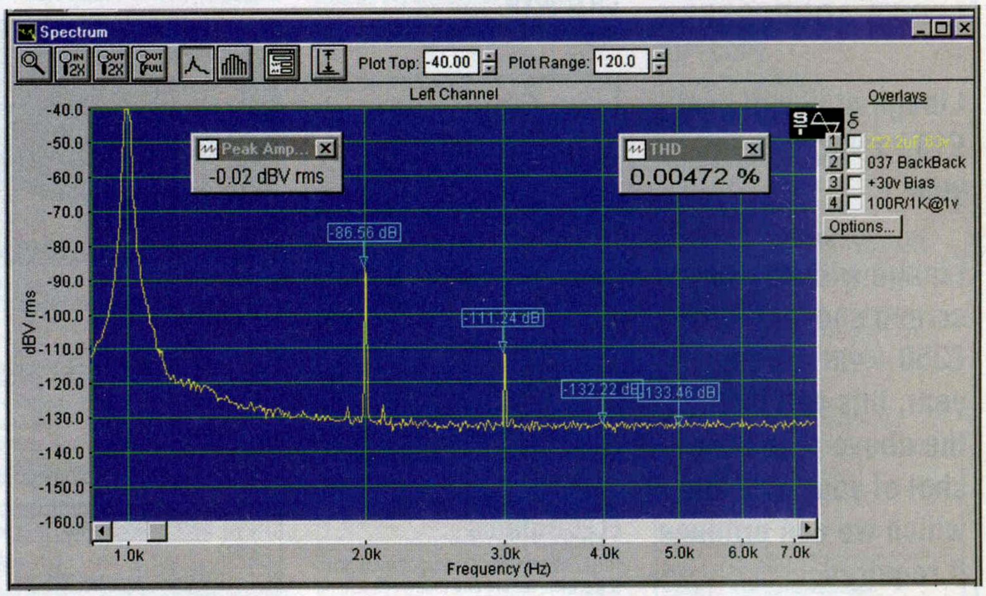

Plot Top: -40.00
Plot Range: 120.0
Peak Amp... -0.02 dBV rms
THD 0.00472 %

Figure 14: With DC bias increased to 30 volts, the back to back connected pair produces almost the same distortion and intermodulation products, as the single polar capacitor of Figure 10. The Bi-polar capacitor produced 0.00225%, half that of the polar or back to back capacitors and no visible intermodulation products. I repeat my questions.

References.

1. Capacitor Sounds part 4 C. Bateman EW November 2002
2. Understanding capacitors - Aluminium and tantalum Electronics World June 1998 p.495. C. Bateman
3. Reference Data for Radio Engineers.Howard Sams & Co. Inc.
4. Understanding capacitors - Ceramic.Electronics World April 1998 p.324 C. Bateman
5. Letters page. D. Self. Electronics World April 1985 p.75
6. Understanding capacitors. C. Bateman Electronics World Dec 1997 p.998

Additional Information

I am currently working to produce a CD ROM which will contain more capacitor details and figures showing many more distortion measurements than could be fitted into this series of articles, together with PDF files able to print the PCB artwork, assembly notes and parts lists.

I hope to have this CD ROM ready soon after my sixth and last article in this series is published, say mid December. Updated details in my next, the last article of this series. Expected cost £15 plus p/p.