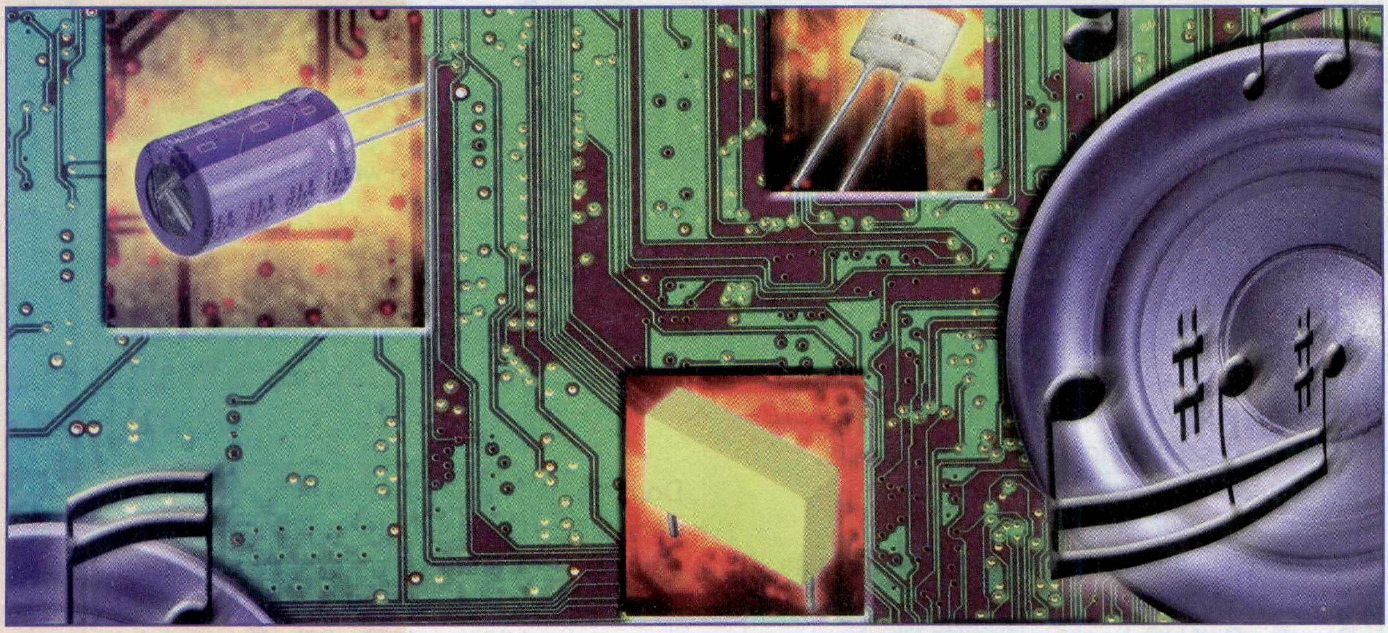

# Capacitor sound 4

**This month, Cyril concentrates on the difficult area of 100nF to 1µF, which usually for size and cost reasons means using metallised PET products**

Readers of my previous articles will have seen that many capacitors do introduce distortions onto a pure sine wave test signal. In some instances distortion results from the loading the capacitor imposes onto its driver. In others, the capacitor generates the distortion within itself.[1]

Capacitors are not categorised for distortion in manufacture, so a distorting capacitor would not be accepted as reject by its maker. Using my easily replicated test method, capacitor distortions can now be measured, surpassing speculation. Equipment designers can now select capacitors for each circuit requirement.

For capacitances of 10nF and smaller, the safe solution is to use C0G ceramic or extended foil/film capacitors. Made with Polystyrene or Polypropylene dielectrics and with leadwires soldered or welded directly to the extended foil electrodes. Avoiding altogether capacitors made with metallised film dielectrics.

These idealised choices minimise all measurable distortion products. While this presents a counsel of perfection, as an engineer I believe prior knowledge of the best and worst extremes should form part of any compromise.

Such near ideal capacitors are not easily

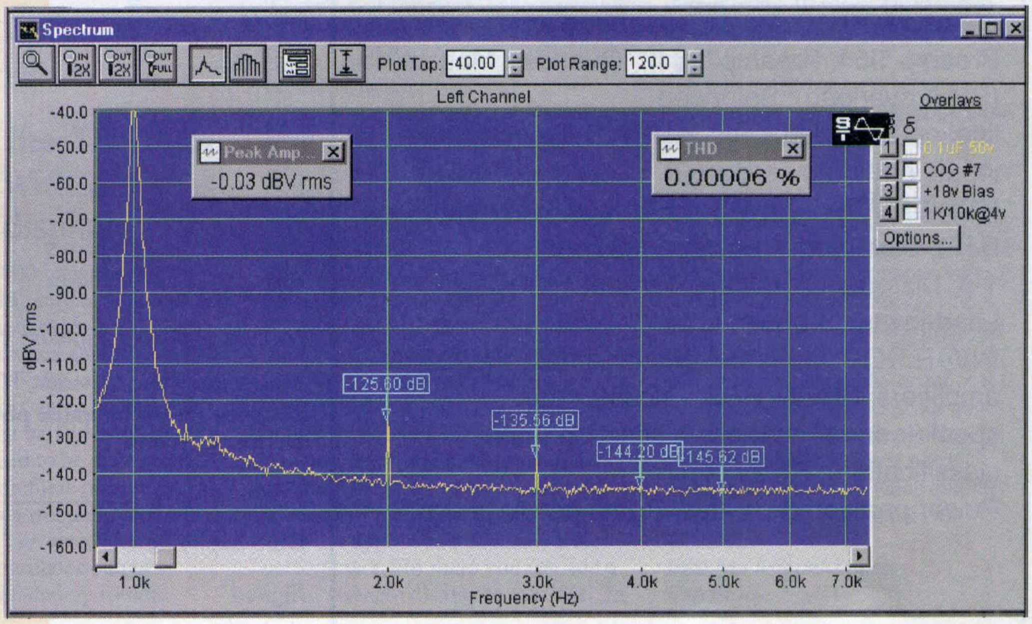


*Figure 1: Distortion measurement of a 100nF 50 volt C0G ceramic, using 100Hz and 1kHz signals at 4 volts with 18 volt DC bias. With no bias this multilayer capacitor measured just 0.00004%. Second harmonic was -131.7dB, other harmonics remained as shown.*

available in acceptable sizes or costs for higher capacitance values. Finding suitable low distortion 0.1μF and 1μF capacitors proved almost impossible. High 'k' BX, X7R, W5R and Z5U capacitors produce far too much distortion for our needs.[1]

Multi-layer ceramics of 100nF 50 volt manufactured in C0G, produce little distortion, with and without DC bias, but are not easily available in small quantities. **Fig. 1**

## The worst capacitor?

A 100nF ceramic disc capacitor is still available. Having the thinnest possible high-k dielectric it provides the worst possible distortion. Despite this, a number of papers found on the internet choose to use this style on which to base their ceramic capacitor measurements and opinions.[2]

Originally called a 'transcap', it pre-dated all low cost 0.1μF film capacitors by many years. It was developed as the smallest, lowest possible cost capacitor, used in pocket transistor AM radios.

A conventional high 'k' ceramic, re-sintered in a reducing atmosphere, becomes a semi-conducting disc measuring a few Ohms resistance. The outer few surface molecules are re-oxidised when the electrode silver is fired in air, to become the dielectric. If sectioned, you will find a black disc, apparently made from charcoal. Using a high power microscope, you may just see an extremely thin, much lighter coloured dielectric layer covering the outer surfaces.[3]

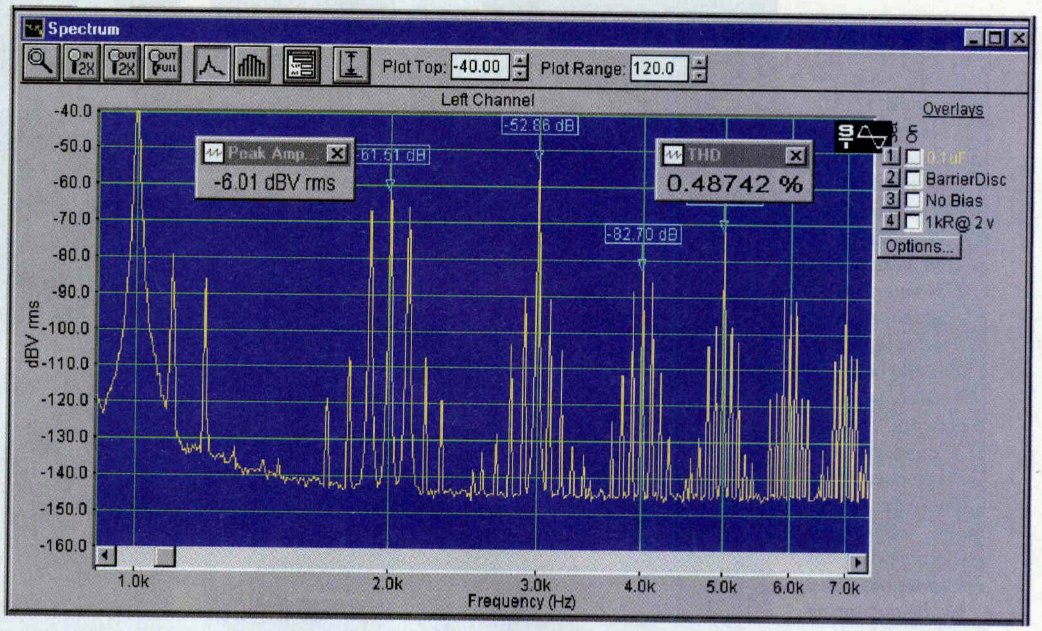


*Figure 2: The worst distortion of more than 2000 capacitor measurements. The test voltage had to be reduced to two volts AC with no DC bias, to avoid harmonics overloading my soundcard.*

Such devices have no place in any audio system. So take care if offered a small ceramic disc, having significantly greater capacitance than found in conventional disc capacitors.[4] **Fig. 2**

## Electrolytics

Tantalum or aluminium electrolytic capacitors are available in these values and form the subject of my next article. Meanwhile we will investigate the options available in film capacitors.

Very low distortion foil and film, Polypropylene (PP) and Polyethylene terephthalate (PET) capacitors are available but are large and usually expensive. The lowest cost, smallest size capacitors, are made with metallised PET.

## Metallised PET capacitors

In the drive, some thirty years ago, to size and cost reduce the 0.1μF capacitor, two problems had to be addressed:

1) First was to produce satisfactory quality, extremely thin metallised PET. In 1978, the Dupont 'Mylar'® capacitor film became available at a thickness of 1.5 microns, some 20 times thinner than human hair.

2) The second was to develop low labour cost methods to wind small capacitor elements. For capacitor makers this was difficult because of the high cost and large numbers of

## Metallised film dielectrics

All common film capacitor dielectrics, other than Polystyrene, can be metallised, to produce a negligibly thick electrode. This metallised coating, usually aluminium, is produced by evaporating metal ingots inside a vacuum chamber. The film is stretched taut and passed through the chamber at controlled speed. To prevent overheating, the film passes over refrigerated rollers.

The metallised coating is so thin, it is transparent. Thickness is monitored by measuring resistance, typically a few Ohms per square, of the metallised surface.

PET and PPS films are easily metallised and provide good adhesion to an evaporated aluminium coating. Untreated Polypropylene has a smooth, waxy surface, which inhibits adhesion.

Various pre-treatments have been applied to PP to improve electrode adhesion. These include mechanical roughening and exposure to high voltage ionisation fields. However, a metallised electrode is often applied to a higher resistance value, i.e. thinner, onto PP than other films.

Contact to the metallised electrode is made by spraying minute metal particles, evaporated inside a high temperature spray gun, onto each end of the capacitor winding. This is known as a 'Schoop' connection. The volume of air needed to propel the metal particles ensures the film surface is only exposed to relatively cool metal and so does not melt.

This 'schoop' metal spray end connection is also used to manufacture some makes of foil and film capacitors and those with double-sided metallised carrier film electrodes. The conductive end spray, short circuits together all turns of a wound capacitor, ensuring minimal self-inductance.

When sufficient 'end spray' thickness has been applied, the capacitor leadwires are attached, usually by soldering or electrical resistance 'welding.' Properly applied this 'schoop' end spray provides a good connection to the electrodes, able to carry significant current. The extremely thin metallised film electrodes obviously cannot handle high currents. When overloaded, visible electrode 'edge burning' occurs, ultimately leading to an open circuit capacitor.

The resistance of the metallised electrode combined with aluminium's temperature coefficient of 0.0039, results in a non-linear resistance. This may at least partially explain some of the larger third harmonic distortions. One simple indicator of the current carrying ability of the 'schoop' end connection into the electrodes used, can be seen in the peak current ratings claimed for the capacitor. For example a 10nF metallised PET capacitor might be rated for 30v/μsec, foil and PET has a much higher current carrying ability, being rated as high as 1000v/μsec.

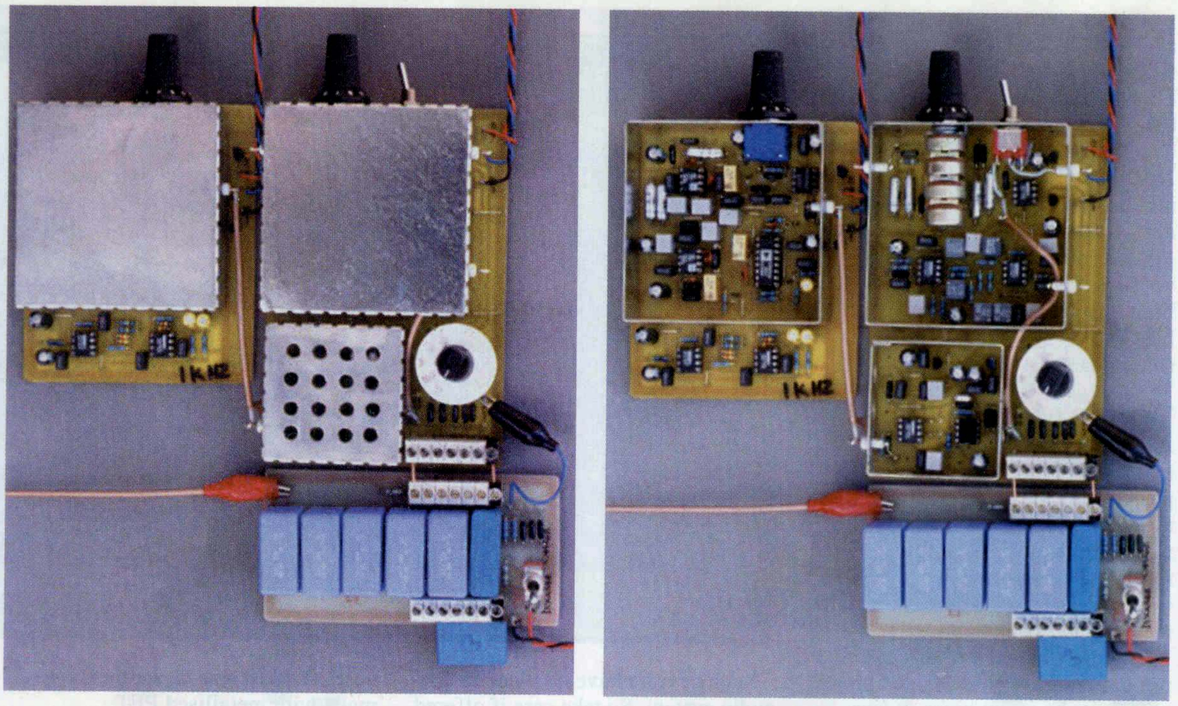

*Figure 3: Finalised measurement system using two test signals, 100Hz and 1kHz, to measure capacitor intermodulation and harmonic distortion, with and without DC bias voltage. The capacitor under test is mounted directly onto the DC bias buffer network. The red crock clip and screened cable supply the 100Hz signal. All screening case lids must be fitted while measuring distortion.*

automatic winding machines needed to produce capacitors in volume.

The major German capacitor makers were leading these developments. Wima with others, worked to develop intricate machines capable of automatically winding individual small capacitors. The Siemens company, now Epcos, sought a different solution, their so-called 'stacked' capacitor.

Despite their name, stacked film capacitors are first wound onto a large diameter wheel, to make a 'mother' capacitor. When all possible processing stages are complete, this 'mother' is sawn into short lengths, each a discrete capacitor element.[5].

During my initial distortion measurements on metallised PET capacitors, I was curious as to whether these two processes would result in different distortion characteristics.

Concentrating my measurements on known wound BC Components type 470 and known stacked Epcos capacitors, I did find differences. The stacked film capacitors usually exhibited an increased third harmonic, compared to this wound type. My initial stocks were too small to be statistically valid, so more capacitors were purchased.

## Wound v Stacked metallised PET

At this time I measured distortion using only a single pure 1kHz tone and no DC bias. With 4 volts dropped across the capacitor, my equipment noise floor was below -140dB. Loaded with a 0.5% metal film resistor, distortion measured 0.00005%. Similarly the best capacitors typically measured 0.00006%, with second harmonic better than -125dB, third and higher harmonics better than -130dB.

Measuring 25 type 470 capacitors I found three having more than ten times higher distortion. Even harmonics were little changed, but third harmonic increased to -100dB, fifth to -115dB. Measuring another 25 capacitors I found two with high distortion. I set a good/bad limit at -120dB, any harmonic exceeding this level being viewed as bad.

The next step was measuring 25 stacked capacitors and I found most measured as bad. Distortions varied from 0.00034% to 0.0018% and many displayed -90dB third harmonics.

Was this difference genuine or was my sample still not statistically significant? Measuring more capacitors, I found some also having increased second harmonic distortions. I had anticipated finding third harmonic variations but did not understand these second harmonic problems,

PET of course has significant

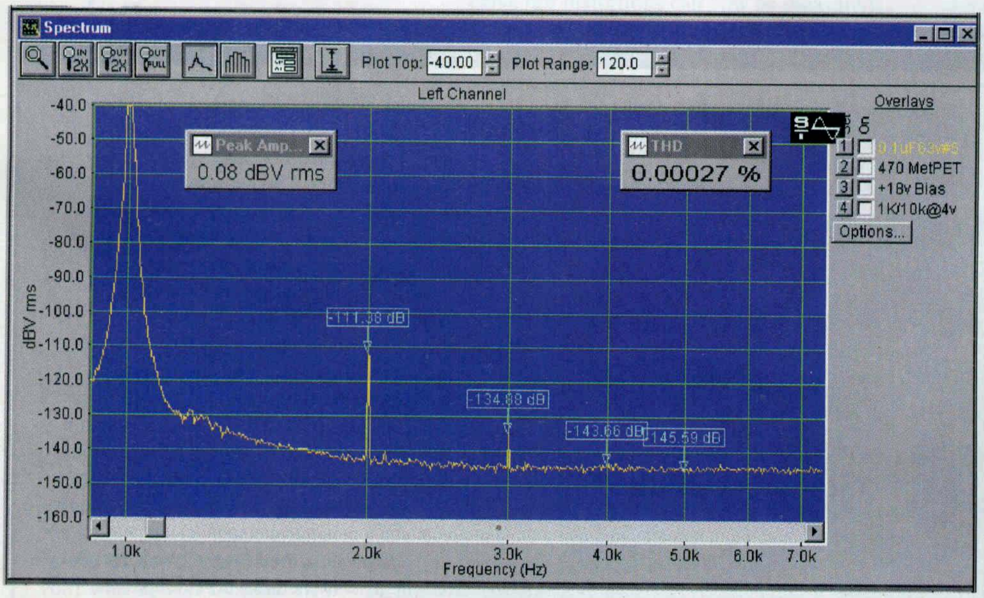


*Figure 4: With no bias, this exceptionally good 0.1μF 63 volt type 470 metallised PET capacitor from BC Components, with magnetic leadwires, measured just 0.00004% distortion. With 18 volts DC bias, the second harmonic increased 22dB from -133.3dB to -111.4dB (distortion increased six times.) Intermodulation products are just visible, either side of 2kHz.*

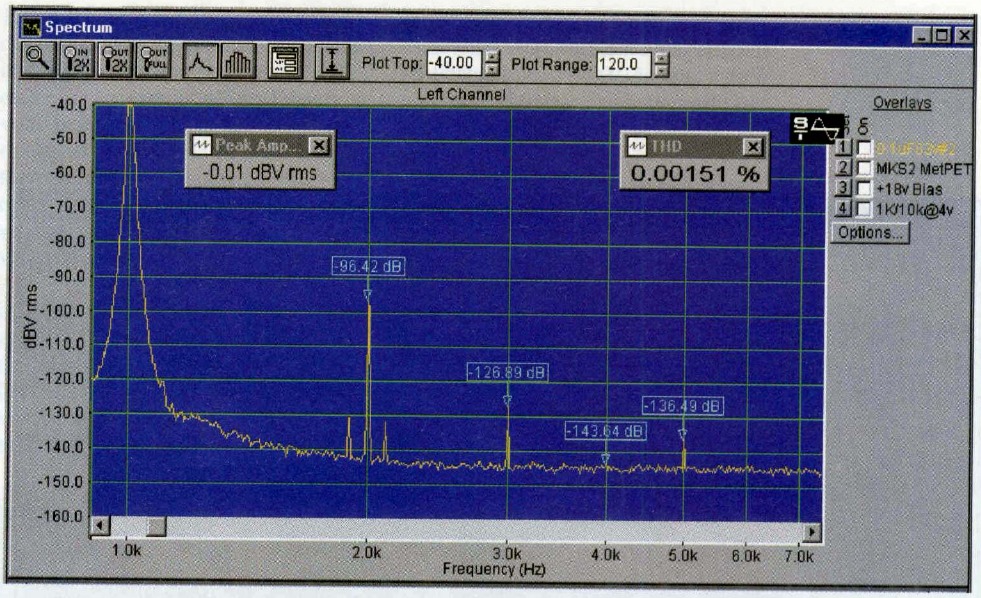


***Figure 5: Distortion measurement of a typical MKS2, with no DC bias measured just 0.00007%. With 18 volts DC bias the second harmonic increased 31dB from -128.3dB to -96.4dB. Intermodulation products and other harmonic levels did not change.***

dielectric absorption, typically 0.5%.[6] Several capacitors, pre-selected as good and very bad distortion, were accurately measured for capacitance and tanδ at 1kHz using my precision bridge, initially unbiased then with 30 volts DC bias. The biggest capacitance change found was less than 0.01% and with tanδ values remaining constant regardless of bias voltage, seemed to rule out any dielectric absorption effects.

Somewhat puzzled, I decided to expand my distortion measurements, changing the measurement stimulus in small steps and varying one test parameter only at a time. I would also look for intermodulation using two test frequencies and explore the affects of change of DC bias voltage. I had no choice but start again, repeating almost 1000 single frequency distortion measurements already saved to disk, both of film and electrolytic capacitors.

## Revised measurements

To prove my DC bias buffer contributed no distortion, I measured my near perfect 1μF KP capacitor. Using 6 volt test signals at 100Hz and 1kHz and 50 volts DC bias, its distortion measured 0.00006%. This DC bias buffer was then used for all measurements. **Fig. 3.**

A 'good' 0.1μF 63v type 470 wound capacitor, tanδ 0.00337, measured similar distortion when tested with no DC bias. Intermodulation was just visible either side of the second harmonic. With 18 volt DC bias, second harmonic increased by 22dB and distortion to 0.00027%. **Fig. 4.**

A batch of Wima MKS2 wound capacitors consistently show increased intermodulation products and third and fifth harmonics. Typical no bias distortions measured around 0.0001%. With 18 volt DC bias the

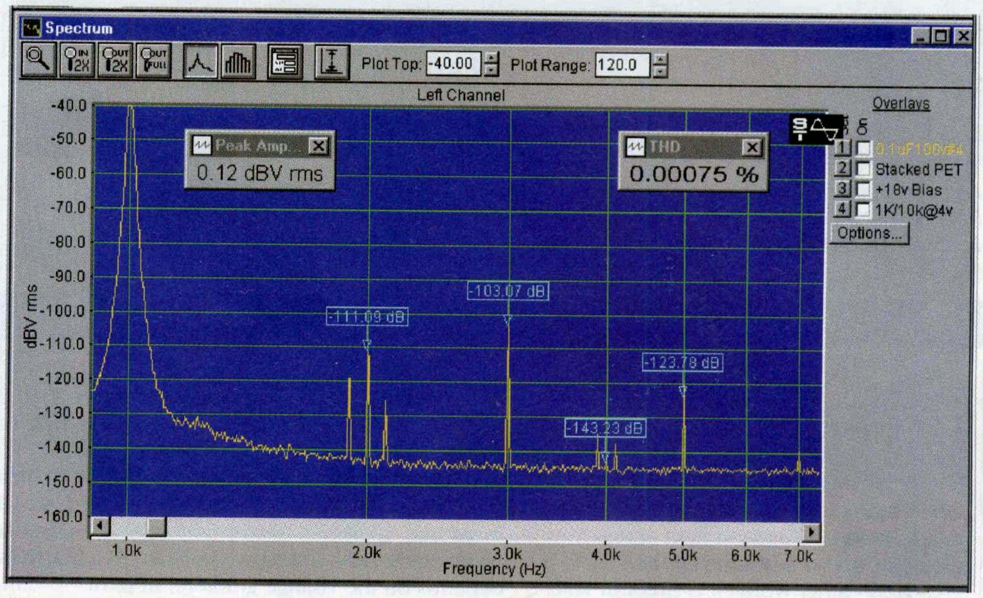


***Figure 6: A 0.1μF 100 volt stacked metallised PET, with magnetic leadwires, displays increased odd harmonics and intermodulation components. The second harmonic of this much larger capacitor made with thicker PET, increased less with DC bias, compared to figures 4 and 5.***

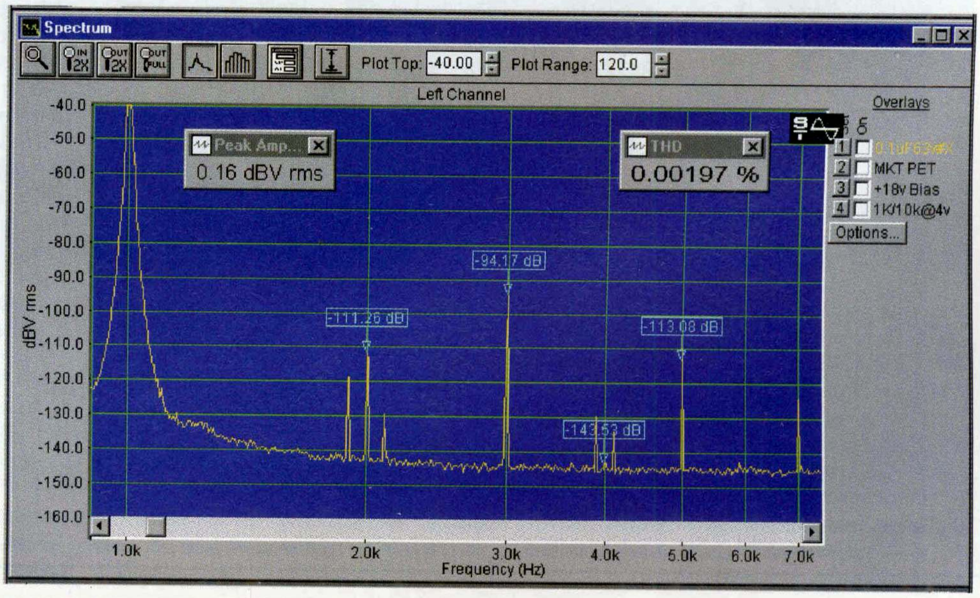


***Figure 7: A different maker's very much smaller, 63 volt stacked metallised PET capacitor with copper lead wires exhibits worse distortions than those shown in figure 6. Notice however a family likeness of distortion components, similar to figure 6 but quite different from figure 4.***

second harmonic increased by 32dB and distortion measured 0.00151%. With a tanδ of 0.00272, this capacitor was dismantled to confirm it was wound construction. **Fig. 5**

A much bigger, 100 volt rated, uncased stacked capacitor with tanδ 0.00352, shows a very high third harmonic level and increased intermodulation products, typical of the construction. Made using thicker dielectric, its second harmonic increased by 16dB when biased with 18 volts. Due to its third harmonic, high distortions were measured with and without bias. **Fig. 6**

Third and odd harmonics vary with AC test signal, but DC bias from 0 volts to 30 volts, has almost no affect. These enormous changes in second harmonic, tested with and without bias, clearly result from the DC bias, dielectric thickness and dielectric absorption. (see box Dielectric Absorption.)

Uncertain of their construction, I ordered just ten MKT capacitors (Farnell 814-192) and all behaved similarly. Exceptionally high distortion with and without bias, dominated by the near -90dB third and -113dB fifth harmonics. With tanδ 0.00371, this capacitor was dismantled to confirm it was stacked construction. **Fig. 7**

With such large variations in harmonic distortion, it seemed all small metallised PET capacitors should be distortion tested, to avoid building obviously 'bad' capacitors into the signal paths of audio equipment

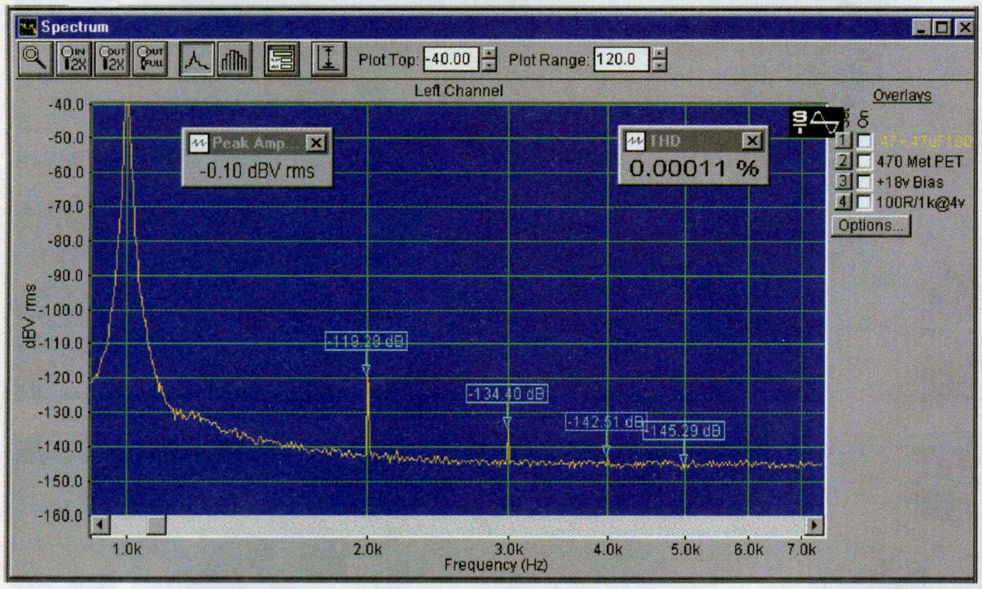


*Figure 8: The first of two plots which explore the effect an increase in metallised PET film thickness might have on distortions. With no bias, distortion of this 100 volt capacitor measured 0.00006%, second harmonic -126.2dB. With DC bias, second harmonic increased by 7dB and distortion to 0.00011%*

## Dielectric Absorption

Two major dielectric characteristics exist, polar and non-polar. By polar I am not referring to an electrolytic capacitor, but to the way the dielectric responds when subject to voltage stress. This stress relates to the voltage gradient across the dielectric and not just the applied voltage. In other words it is stress in volts per micron, which matters.

Non-polar dielectrics, for example 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 however are affected to some extent, increasing roughly in line with their dielectric constant or 'k' value. This 'k' value is the increase in measured capacitance when the chosen dielectric is used to replace a vacuum or more usually, air.

When a dielectric is subject to voltage stress, electrons are attracted towards the positive electrode. The electron spin orbits become distorted creating mechanical stress and a so-called 'space charge' within the dielectric. This mechanical stress produces some heat rise in the dielectric and a power loss, called dielectric loss. Non-polar dielectrics exhibit very small power or dielectric losses. Polar dielectrics are much more lossy. Having been charged to a voltage, it takes much longer for the electron spin orbits in a polar dielectric to return to their original uncharged state. Polar dielectrics produce easily measured 'dielectric absorption' effects.

Dielectric behaviour with voltage depends on the voltage gradient, in terms of volts/micron as well as on the characteristics of the dielectric. Its effects are more readily apparent with very thin dielectric. The lowest voltage, 50 and 63 volt rated metallised PET film capacitors are often made using 1 micron or thinner film. As will be seen in my next article, the dielectric used to make small low voltage electrolytics is perhaps one hundred times thinner. Consequently we should anticipate increased effects from dielectric absorption.

Foil and film capacitors cannot 'self heal' so must be made using relatively thick dielectric films. As a consequence we find that foil and film PET capacitors can provide low distortion, even when subject to DC bias voltages.

Dielectric absorption is usually measured by fully charging the capacitor for several minutes to a DC voltage, 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' DC 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 descriptions can be found, describing smearing, time delays and compression. My AC capacitance and distortion measurements, simply do not support these claims. The main characteristic I have found, which clearly relates to dielectric absorption, is the magnitude of the second harmonic. This does increase with applied AC or DC voltage stress and especially so with thin materials, having known higher dielectric absorption. For example, the PET (Polyethylene Terephthalate)and PEN (Polyethylene Naphthalate) dielectric films have almost identical characteristics except for dielectric absorption. Comparative distortion measurements with and without DC bias, made on metallised PEN and metallised PET capacitors, show that PEN capacitors do produce much larger second harmonics. The PEN material at 1.2%, has almost three times greater dielectric absorption than PET[6]

## The 1μF problem

To approach our idealised capacitor we need the small size provided by metallised PET, the low distortions found using Polypropylene and low cost. These qualities could be approached using metallised Polycarbonate, but Polycarbonate capacitors have become extremely expensive. With the production of Bayer Makrofol Polycarbonate film having ceased, metallised Polycarbonate capacitors may disappear.

A great many 0.1μF metallised PET capacitors had been measured, without finding clear reasons for their widely differing distortions. Would measurements at 1μF help?

I decided to measure the same make and style, rated at both 63 volt and 100 volt, to explore the D. Self comment that 63 volt capacitors exhibit ten times more distortion than 100 volt.[7] Provided the maximum capacitance possible at these voltages in both case sizes is obtained, dielectric absorption effects related in volts per micron to the differing film thickness used should be observed. It seemed probable that the 63 volt capacitor would exhibit increased second harmonic compared to the 100 volt version.

I choose to measure the 470 style capacitors, because 0.47μF at 100 volt and 1μF at 63 volt, were the maximum capacitances available in the case size. I soldered together several pairs of 0.47μF to produce near 1μF 100 volt capacitors.

Measured within a few minutes of each other, with no bias voltage, the 63 volt and 100 volt capacitors measured almost identically, with distortion at 0.00007% and 0.00006% respectively.

Re-measured with 18 volt DC bias, the third and higher harmonics were unchanged but second harmonic levels increased for both voltage ratings. Second harmonic for the 63 volt capacitors increased by +12.5dB, the 100 volt capacitors by +7dB, giving measured distortions of 0.00024% and 0.00011% respectively. **Fig. 8** These figures equate well with the expected differences in film

## 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 PCBs, 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.

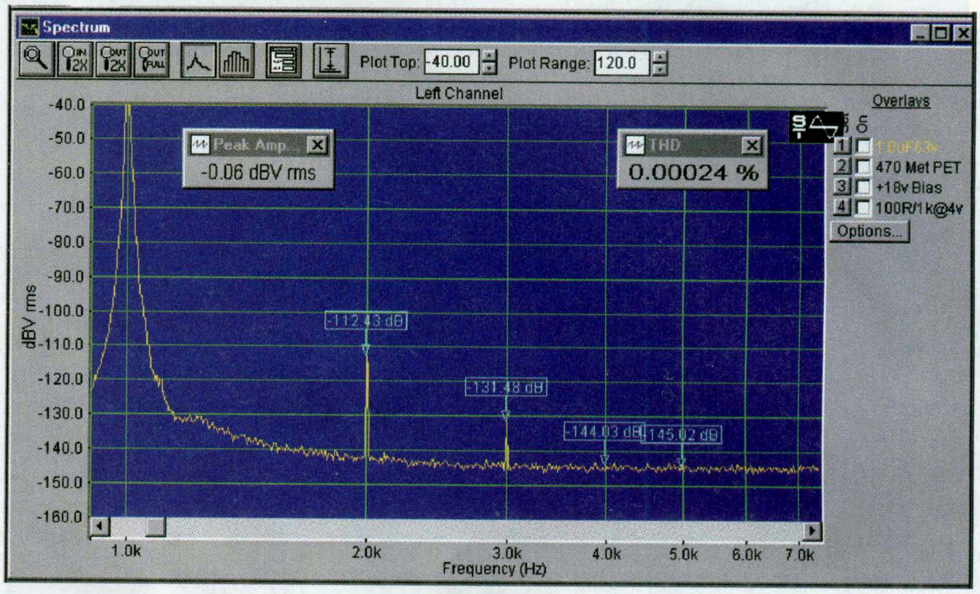


*Figure 9: Distortion of the 63 volt capacitor, same make comparison with figure 8. With no bias, distortion measured just 0.00007% with second harmonic at -124.9dB. With DC bias, second harmonic increased by 12.5dB. At 0.00024%, distortion is double that of the 100 volt capacitors.*

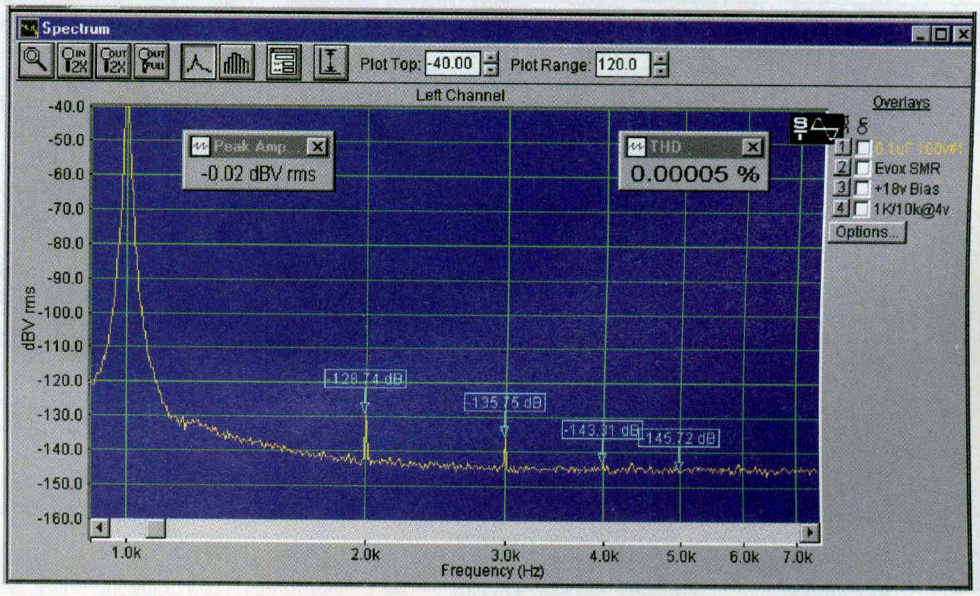


*Figure 10: This 0.1μF 100 volt Evox Rifa SMR capacitor, provides a superb low distortion performance with or without DC bias, even as high as 30 volts and no intermodulation products were seen.*

thickness and confirmed the effect dielectric absorption has on second harmonic distortion. (see box Dielectric Absorption.) Some factor other than rated voltage, must account for Douglas's reported observation. **Fig. 9**

Further measurements on 1μF metallised PET capacitors, using 25 pieces of the wound type 470, and a similar quantity of stacked film capacitors, revealed nothing new. Distortion patterns established by the smaller capacitors were being repeated. I also had 10 pieces of wound capacitors type 370, dated 1995. These produced harmonic levels with and without bias remarkably similar to those measured on the MKS2 types.

## Possible mechanisms

These tests clearly illustrate how audible problems can exist using metallised PET capacitors in low distortion audio. I now sympathise with listeners who complain about amplifier sounds, when using metallised PET capacitors.

Lacking the facility to assemble test capacitors using known differences in materials and processes, I can only speculate as to possible reasons for the different third harmonic distortion levels I found. These may result from differences in manufacture of the basic film or the vacuum deposition of the metallised electrodes, processes that vary from maker to maker.

It might even be as simple as the electrode metallisation thickness used. Perhaps thickness gives the wrong impression, this aluminium coating is so thin, like mirror sunglass lenses, it is quite transparent. Its thickness is measured in Ohms/square, typically some 2 to 4 Ohms.

One convenient explanation for these differences might be the use of copper versus magnetic leadwires. Not so, the lowest distortion, type 470 metallised PET capacitors tested use magnetic leads whilst the worst distortion stacked types used copper.

More likely are differences in the metal compositions and spray application methods used, to produce the 'schoop' end connections.[5] Aluminium metallised electrode has an electro-chemical potential of +1.66 volt, magnetic leads +0.44 volt, copper wires -0.337 volt. For the 'schoop' connection, a variety of other metals are used, having intermediate, mostly positive potentials. Possible 'Seebeck' effects should not be ignored. (see box Metallised film dielectrics.)

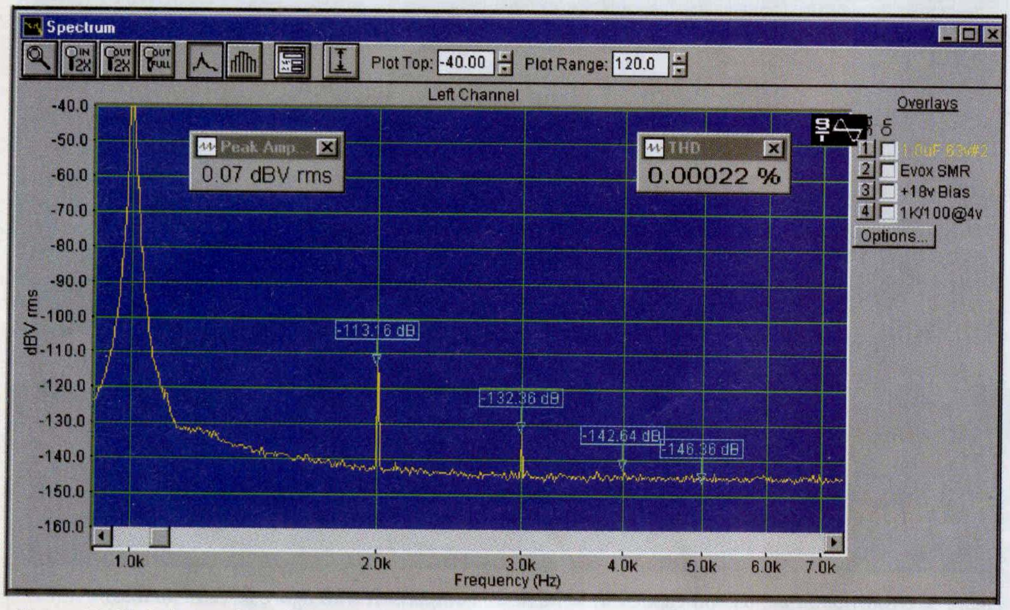


*Figure 11: Little larger than their 0.1μF, this 1.0μF 63 volt SMR capacitor from Evox Rifa behaves impeccably with or without DC bias up to 10 volts. With increased DC bias its second harmonic does increase but no intermodulation products were seen.*

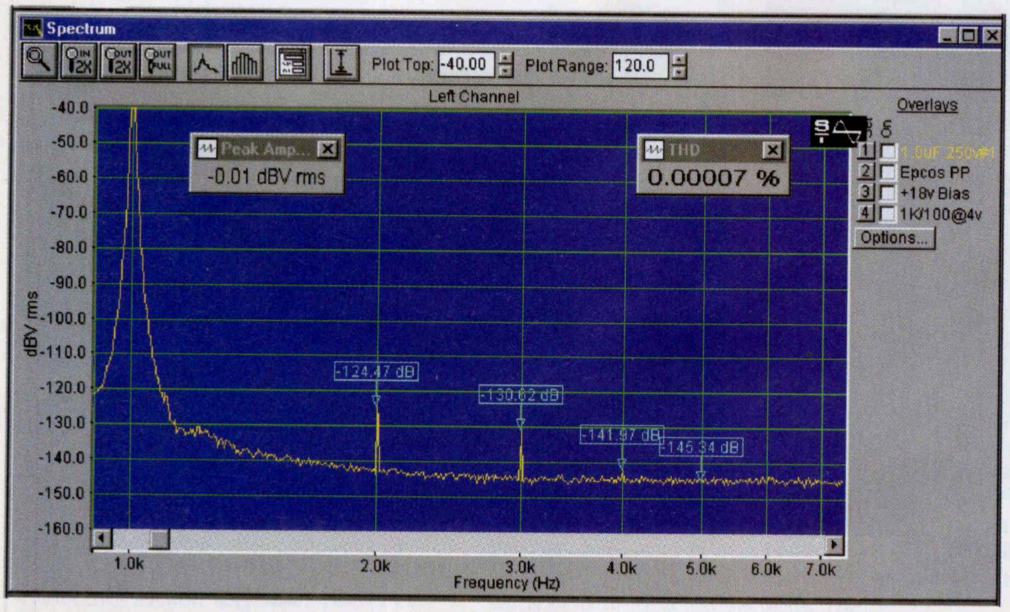


*Figure 12: If you have room for a capacitor with 22mm lead spacing, this 1.0μF 250 volt Epcos with DC bias voltage, distorts less than most capacitors with no bias.*

## Intermodulation distortion

From many measurements using AC voltages from 0.5 to 6 volts, intermodulation products are produced in metallised PET capacitors according to the level of third harmonic the capacitor produces. For example a 'bad' capacitor exhibits intermodulation when subject to much less than 1 volt AC. A capacitor developing smaller third harmonic, shows no visible intermodulation until its AC voltage exceeds 3 volts. **Fig. 4**

The best metallised PET capacitors produced almost no distortion with no DC bias, but when used to block DC, second harmonic distortion increased rapidly with increasing DC bias voltage. Depending on circuit arrangements, many capacitors could produce audible distortions. Perhaps this should not surprise us. Audiophiles have claimed to be able to 'hear' PET capacitors for many years.

I believe that for 0.1μF to 1μF values, metallised PET capacitors should first be distortion tested. Because of their rapid increase in second harmonic with DC bias, they should not be used with significant DC bias, relative to their rated voltage, in high quality audio equipment. Having so far failed to find a physically small, economic,

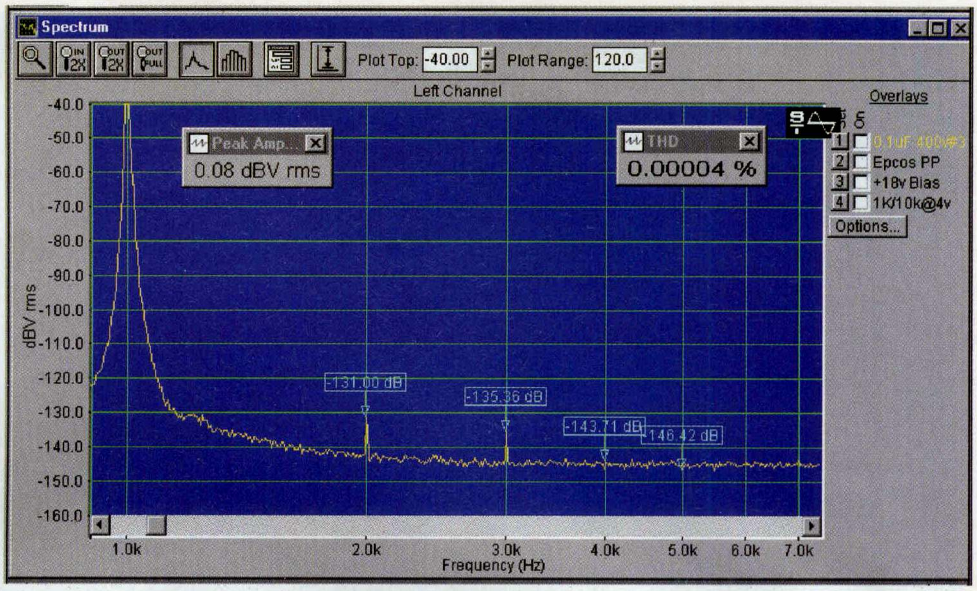


*Figure 13: As good as Polystyrene? Distortions from this Epcos 15mm lead spacing 0.1μF 400 volt capacitor barely change even with 30 volts DC bias.*

low distortion solution, is one possible?

## Polyphenylene Sulphide

A much better but little used, slightly more expensive dielectric has been available for many years.[8] It is available metallised down to 1.2 microns and with a 'k' of 3, it provides capacitors slightly larger than metallised PET.[6] It has many other benefits. Usable to 125ºC, it provides a near flat temperature coefficient and tanδ slightly higher than metallised Polypropylene. It has a small dielectric absorption of 0.05%, better than Polycarbonate and ten times better than PET.

Like Polycarbonate, Polystyrene and COG ceramic, it provides superb long-term capacitance stability, changing only 0.3% maximum in 2 years. It seems Polyphenylene Sulphide (PPS) should provide acceptable size, low distortion capacitors.

I used 0.1μF 50 volt, 5mm centres Evox Rifa SMR metallised PPS capacitors, in my tanδ meter assemblies. Measurements of 25 pieces displayed extremely low distortion. This stock was purchased from RS, who has dropped the product from its catalogues, so I sought another stockist. The Farnell web site recently listed a small selection of Evox Rifa Polyphenylene Sulphide capacitors. Maximum stock value in 5mm lead spacing is 10nF, with up to 1μF at 63 volt in 10mm centres and at 100 volt in 15mm. The largest value, 3.3μF at 63 volt, has 15mm centres.

The 0.1μF 100 volt SMR produced superb results with and without DC bias voltage. **Fig. 10** The 1μF 63 volt produced superb results if biased to less than 10 volts but with increasing bias, second harmonic distortion increases. The larger 1μF 100 volt should be less sensitive. **Fig. 11** Both SMR types tested have small case size and 10mm lead spacing.

## Bigger the better?

Another new Farnell line is Polypropylene capacitors from Epcos (Siemens). The second harmonic of the 1μF 5% 250v B32653, with 22mm centres, changes little with DC bias up to 30 volts, distortion is then 0.00008%, a superb performance. **Fig. 12** The 0.1μF 5% 400v 15mm centres B32652, measured 0.00005% with 30 volts DC bias. **Fig. 13** Distortions from these 0.1μF and 1μF Epcos capacitors were not bettered by any similar sized capacitor I tested. With double the PCB footprint of the SMR types they may not fit your space. No doubt these new lines will appear in the Farnell catalogue.

## Maintaining designed performance

Having measured several hundred metallised PET capacitors, I found many with extremely low distortions if measured without DC bias. I also found far too many showing very bad distortions, both DC biased and unbiased, yet metallised PET capacitors continue to be used in the signal paths of high quality audio amplifier designs.

To ensure the claimed performance of a published audio circuit can be repeated, the designer should declare the make, model and rated voltages of the capacitors. Simply stating ceramic, film etc. is totally unacceptable. These tests illustrate how a capacitor with an acceptable single frequency distortion test, can produce significant intermodulation on audio when presented with multiple frequencies.

Many years ago Ivor Brown presented the case that amplifier tests should comprise three test signals. This seems to have been completely ignored, at least in EW amplifier design articles.[9] Single tone 1kHz amplifier harmonic distortion tests ignore distortions caused by the rising impedance of capacitors at low frequencies. It is now clear that large amplitude bass notes and drum beats in music can result in peculiar intermodulation distortions, in an otherwise apparently good amplifier.

For my part I shall disregard any published audio designs which do not report low frequency intermodulation distortion claims or low frequency harmonic distortion results, especially if the capacitors used are not properly chosen and adequately defined.

In my next article we introduce that most complex of capacitors, the electrolytic, then explore which produces the least distortion at 1μF, a metallised film or an electrolytic capacitor. ■

Some of the illustrations in last month's article were accidentally reduced too much, resulting in some of the text bordering on being illegible. Those diagrams are repeated over the next pages in larger form. Apologies.

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