Capacitor Sounds 4 - capacitances from 100 nF to 1 µF.

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Readers of my previous articles will have seen that many capacitors do introduce distortions onto a pure sinewave 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. **Ref.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 easily test and select capacitors for each circuit requirement.

For capacitances of 10 nF 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 or using 'Schoop' metal spray end connections.

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.

Problem area.

Such near ideal capacitors are not easily available in acceptable sizes or costs for higher capacitance values. Finding suitable low distortion 0.1 µF and 1 µF capacitors proved almost impossible.

High 'k' BX, X7R, W5R and Z5U capacitors produce far too much distortion for our needs. **Ref.1**

Multilayer ceramics of 100 nF 50 volt manufactured in C0G, produce little distortion, with and without DC bias, but are not easily available in small quantities. COG can provide very low distortion, comparable with the best film capacitors. see **Fig. 1**

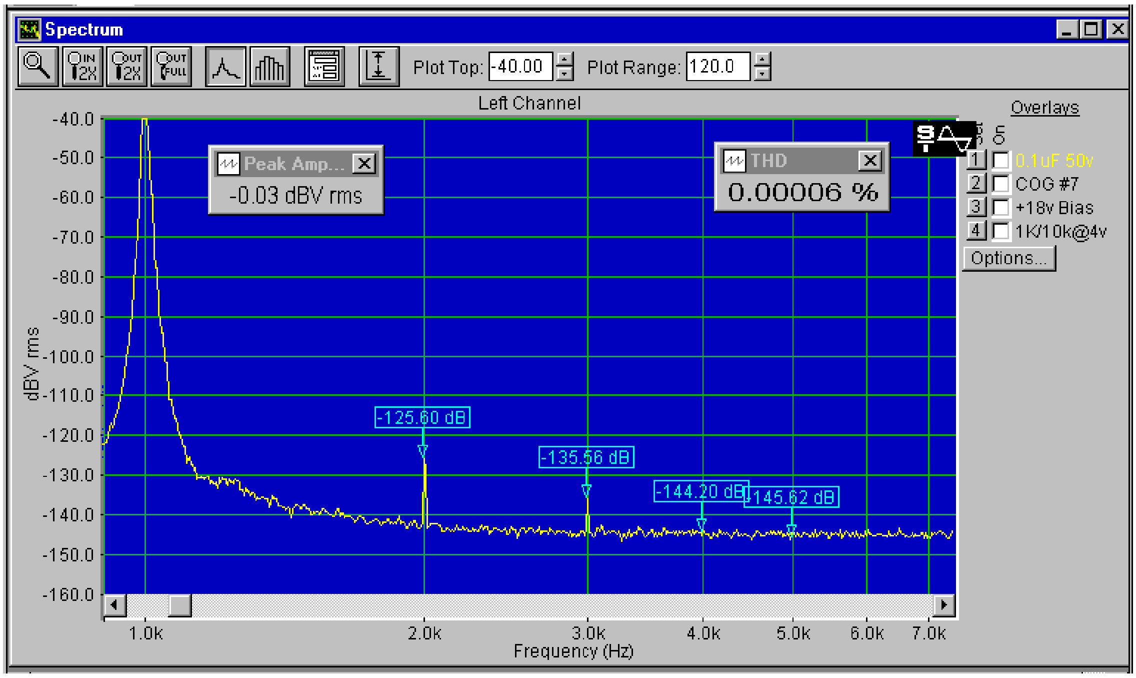

Fig 1) Distortion measurement of a 100 nF 50 volt C0G ceramic, using 100 Hz and 1 kHz signals at 4 volts and 18 volt DC bias. With no DC bias this multilayer capacitor measured just 0.00004%. Second harmonic was -131.7 dB, other harmonics remained as shown.

The worst capacitor?

A 100 nF 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 Internet, choose to use this style on which to base their ceramic capacitor measurements and opinions. This mistake resulted in a totally biased prejudice against using COG capacitors for audio. **Ref.2**

Originally called a 'transcap', it pre-dated all low cost 0.1 µF film capacitors by many years. It was developed as the smallest, lowest possible cost decoupling capacitor, used in transistor pocketable 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 of this 'Barrier Layer' disc capacitor. 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. Performance of a 'Barrier Layer' capacitor bears no resemblance to that of any other ceramic capacitor so must not be taken as representing other styles of capacitor. This barrier layer construction does produce a uniquely bad, exceptionally high distortion. **Ref.3**

Such devices have no place in any audio system. So take care if offered a small ceramic disc, having significantly greater capacitance than the few hundred pF found in conventional ‘Type 1’ ceramic disc capacitors. **Ref.4** see **Fig. 2**

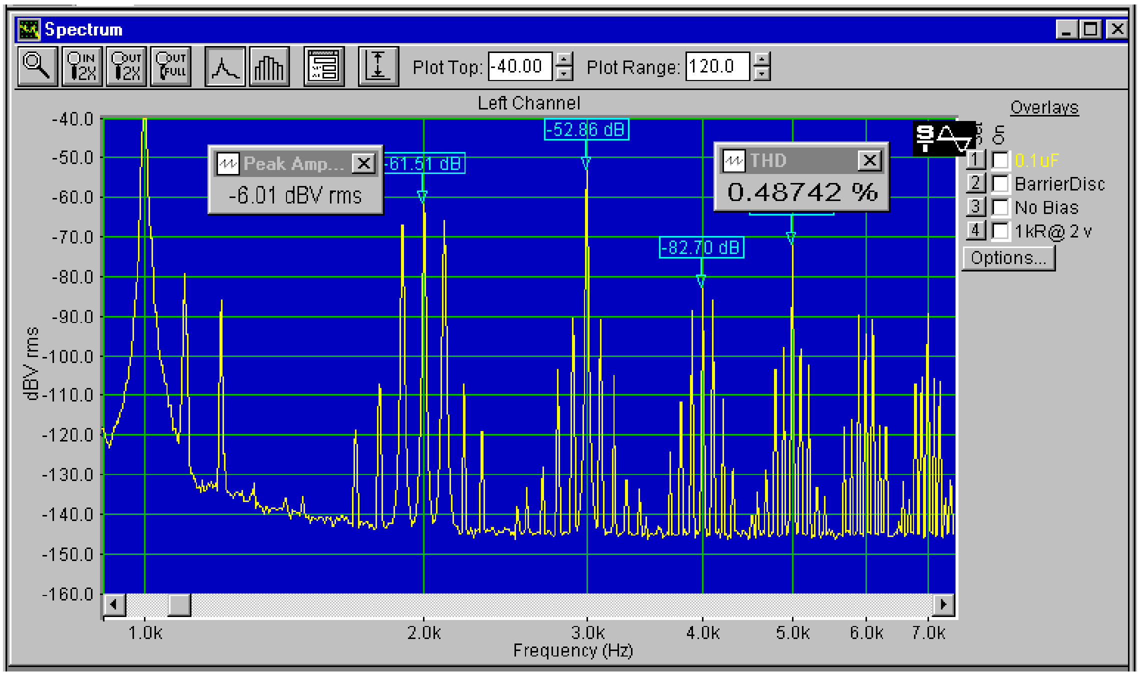

Fig 2) The worst distortion of more than 2000 capacitor measurements. The test voltage had to be reduced to two volts AC with no DC bias, to avoid harmonics overloading my soundcard.

This test was made using only 1 kHz, even worse intermodulation is produced using two or more test signals.

With the exception of figure 2, all distortion plots in this article used two test frequencies, 1 kHz and 100 Hz both set to 4 volts. To ensure all test plots also resulted from applying similar test currents, source impedances for 100nF types used 1k for 1 kHz 10k for 100 Hz, while 1.0 µF used 100R for 1 kHz, 1k for 100 Hz. These test stimuli can be read upper right on each plot.

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.
In the drive, some thirty years ago, to size and cost reduce the 0.1 µF 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 1.5 microns thick, some 20 times thinner than human hair.
2) Second was to develop low labour cost methods to wind small capacitor elements. For the makers this was difficult because of the high cost and large numbers of 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. **Ref.5.**

During my initial distortion measurements on metallised PET capacitors, I was curious 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 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 1 kHz tone and no DC bias. With 4 volts dropped across the capacitor, my equipment noise floor was below -140 dB. 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 -125 dB, third and higher harmonics better than -130 dB.

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 -100 dB, fifth to -115 dB. Measuring another 25 capacitors I found another two with high distortion.

I set an arbitrary good/bad limit at -120 dB, any harmonic exceeding this level being viewed as bad.

Measuring 25 stacked capacitors, using this criteria, I found most measured as bad. Distortions varied from 0.00034% to 0.0018% and many displayed -90 dB 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, which can result from non-linear connections in the capacitor, but did not understand these second harmonic problems.

PET of course has significant dielectric absorption, typically 0.5%, when tested at the rated voltage of the capacitor. **Ref.6** Several capacitors, pre-selected as good and very bad distortion, were accurately measured for capacitance and tanδ at 1 kHz 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 would measure more capacitors for voltage coefficient and dielectric absorption.

I had no choice but start again, repeating almost 1000 single frequency distortion measurements already saved to disk, but this time using two test frequencies, with no DC bias and using various DC bias voltages, both of film and electrolytic capacitors.

Revised measurements.
To prove my DC bias buffer contributed no distortion, I measured my near perfect 1 μF KP capacitor. Using 6 volt test signals at 100 Hz and 1 kHz, with and without 50 volts DC bias, its distortion measured 0.00006%. This DC bias buffer was then used for all these new measurements including all those made with 0 volt DC bias. see **Fig. 3**

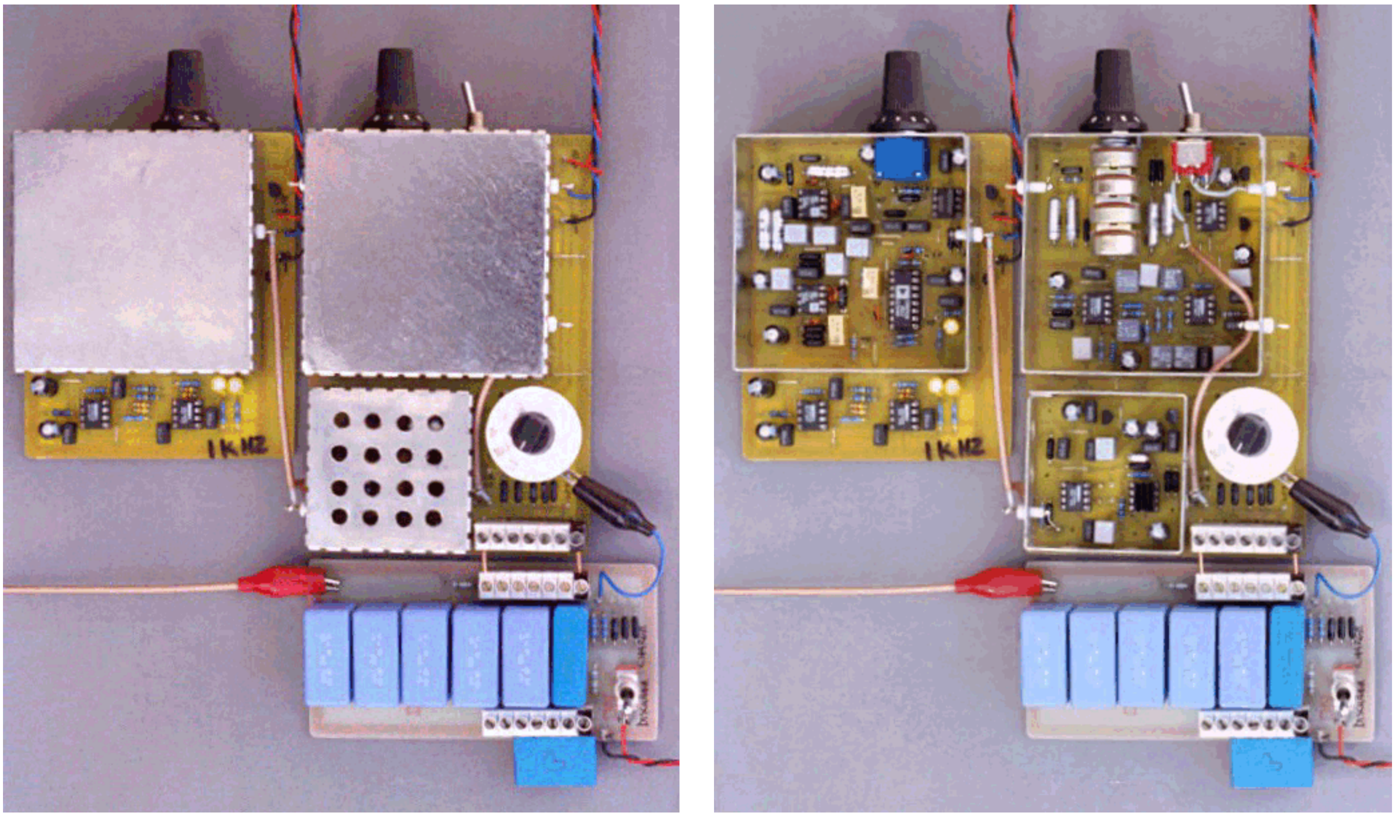

Fig 3) Finalised prototype measurement system using two test signals, 100 Hz and 1 kHz to measure capacitor intermodulation and harmonic distortion, with and without DC bias voltage. The capacitor under test is mounted directly onto the DC bias buffer network. The Red crock clip and screened cable supply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

A ‘good’ 0.1 µF 63 volt 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%. Voltage coefficient measured 0.0% up to 30 volt bias, DA measured 0.107% see **Fig. 4**

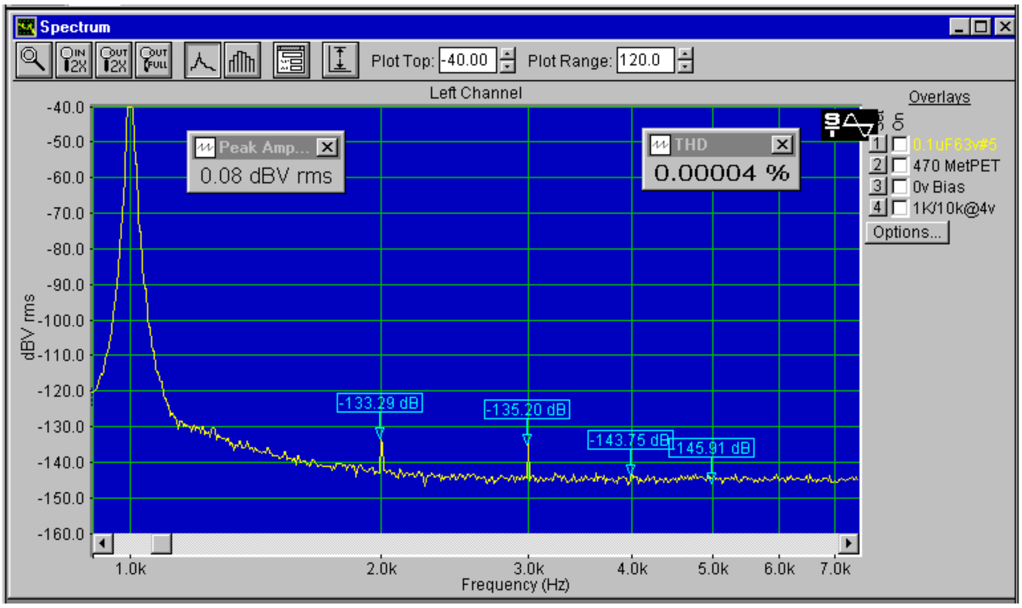

Fig 4A) With no bias, this exceptionally good 0.1µF 63 volt type 470 metallised PET capacitor, from BC Components, made with magnetic leadwires, tested at 4 volts 1 kHz/100 Hz measured 0.00004% distortion. Intermodulation is just visible either side of the second harmonic.

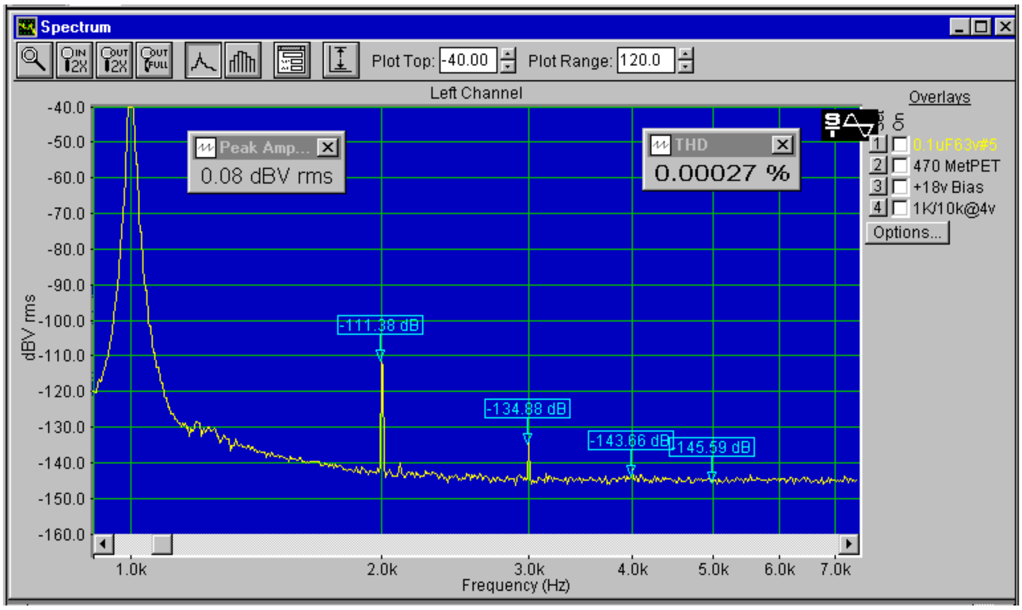

Fig 4) With 18 volts DC bias, the second harmonic increased 22 dB from -133.3 dB to -111.4 dB, distortion increased six fold, but third harmonic has not changed. Intermodulation products also are unchanged, just visible, either side of 2 kHz.

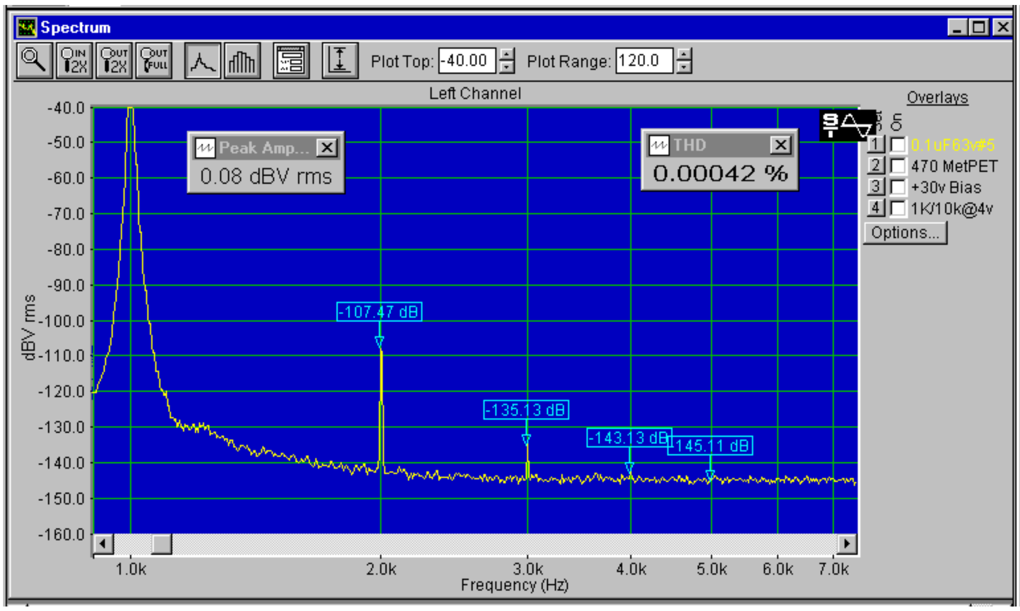

Fig 4B). When bias was increased to 30 volt DC second harmonic became -107dB and distortion increased to 0.00042%. However as can be seen, increase of DC bias, has little or no effect on the level of third harmonic or the intermodulation distortions, which remain almost invisible.

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 second harmonic increased 32 dB and distortion measured 0.00151%. Voltage coefficient was less than 0.01%, DA measured 0.147%. see **Fig. 5**

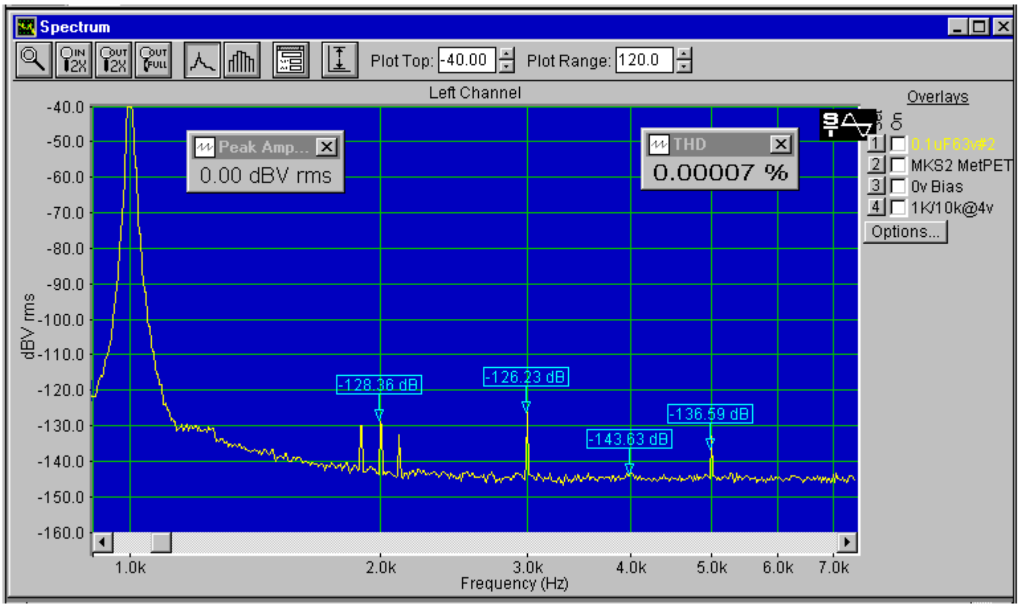

Fig 5A) Distortion measurement of a typical 0.1 µF 63 volt MKS2 with no DC bias measured just 0.00007%. All other samples measured, consistently show similar increased intermodulation products and third and fifth harmonics when compared to the B C Components style 470 of figure 4.

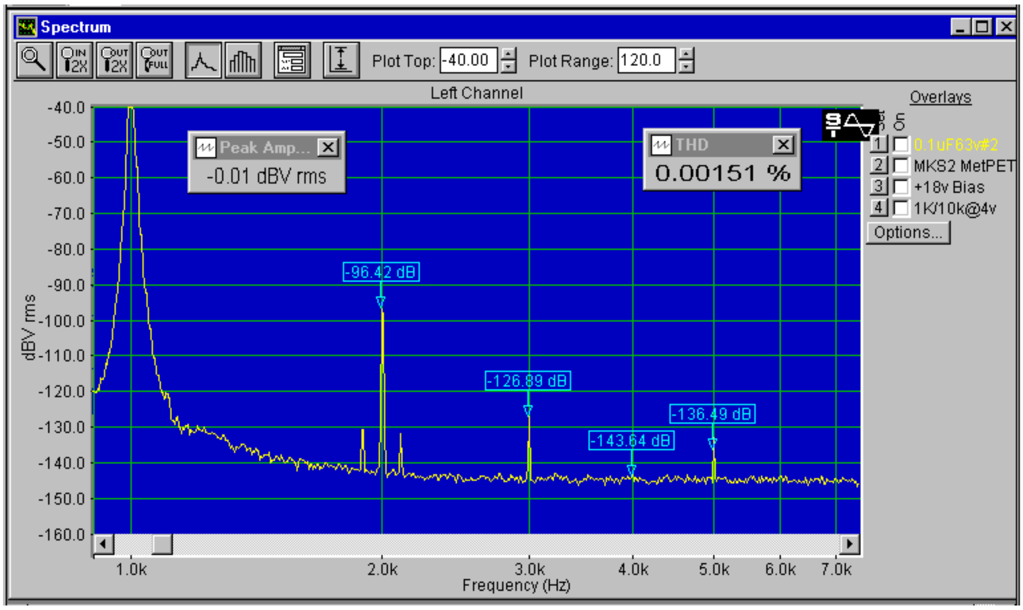

Fig 5) With 18 volts DC bias, second harmonic increased 32 dB from -128.3 dB to -96.4 dB, distortion increased to 0.00151%.

Intermodulation products and other harmonic levels did not change.

With a tanδ of 0.00272, this capacitor was dismantled to confirm it was wound construction.

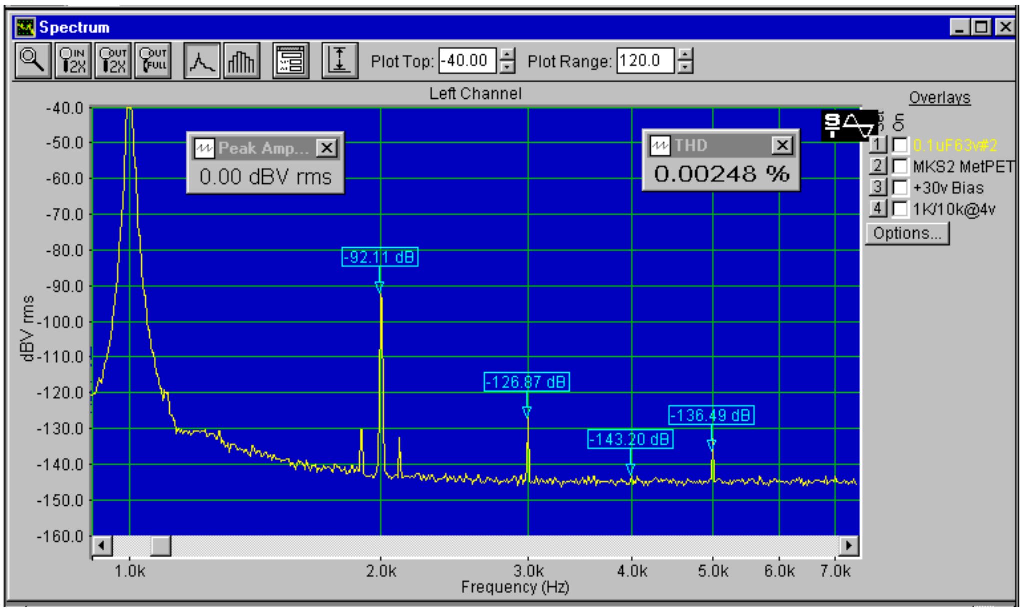

Fig 5B) When bias was increased to 30 volt DC second harmonic became -92.1dB and distortion increased to 0.00248%. However as can be seen, increase of DC bias to 30 volt again has little or no effect on the level of third or fifth harmonics which remain notably higher than with the 470 style.
Intermodulation distortions remain clearly visible around -130dB.

A much bigger, 100 volt rated, un-cased 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 16 dB when biased to 18 volts. Due to its third harmonic, high distortions were measured with and without bias. se**e Fig. 6**

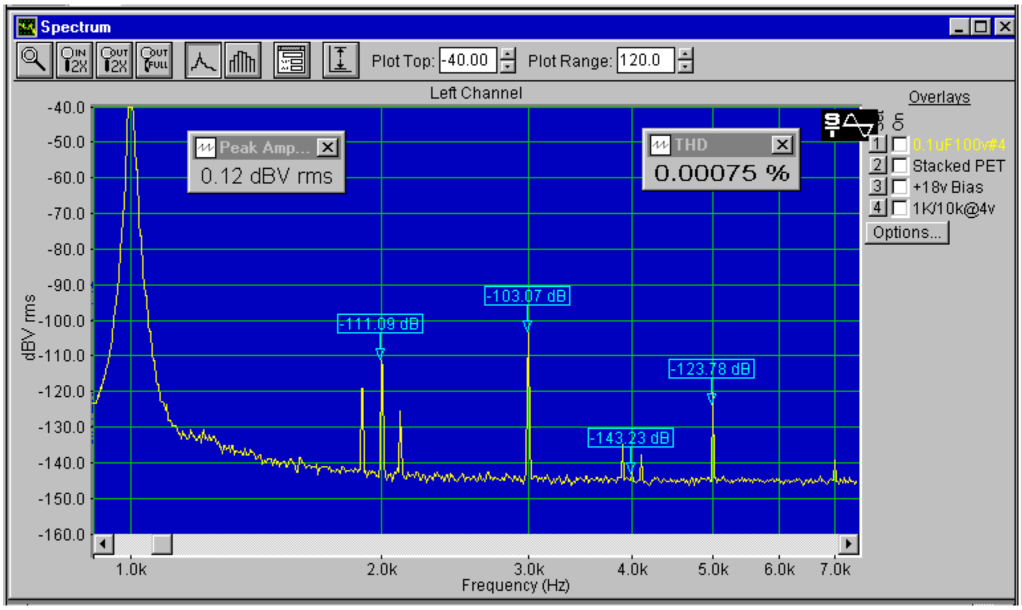

Fig 6) A 0.1 µF 100 volt stacked metallised PET, with magnetic leadwires, displays much increased odd harmonics and intermodulation components. Second harmonic of this much larger capacitor made with thicker PET, increased less with DC bias, compared to figures 4 and 5. Third and odd harmonics do vary with AC test signal, but DC bias from 0 volts to 30 volts, has almost no affect.

These enormous changes in second harmonic found in metallised PET capacitors tested with and without DC bias, clearly result from bias voltage, dielectric thickness and dielectric absorption, not from their negligible, less than 0.01% voltage coefficient.

Box **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. It’s 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.

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 found in magazines and on Internet, describing smearing, time delays and compression. My AC capacitance and distortion measurement results, 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. **Ref.6 End of Box.**

Uncertain of their construction, I ordered just ten MKT capacitors (Farnell 814-192), all behaved similarly. Exceptionally high distortion with and without bias, dominated by the near -90 dB third and -113 dB fifth harmonics. Voltage coefficient measured less than 0.01%, DA measured as 0.173%. see **Fig. 7**

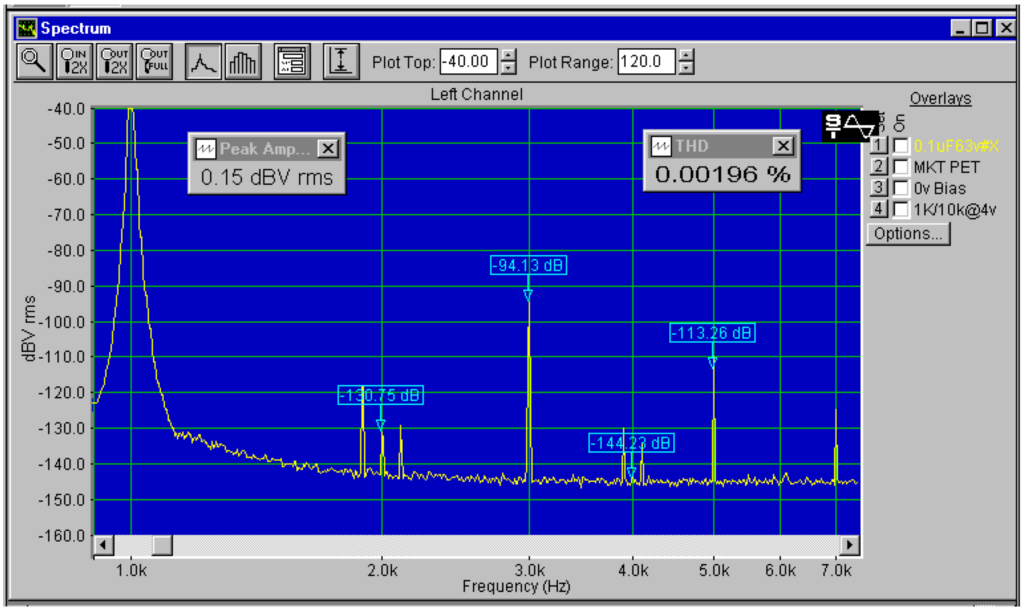

Fig 7A) A different makers very much smaller, 0.1 µF 63 volt stacked metallised PET capacitor, made with copper lead wires, tested with no DC bias, exhibits worse distortions than those shown in figure 6.

Notice however a family likeness of distortion components, similar to figure 6 but quite different from figure 4.

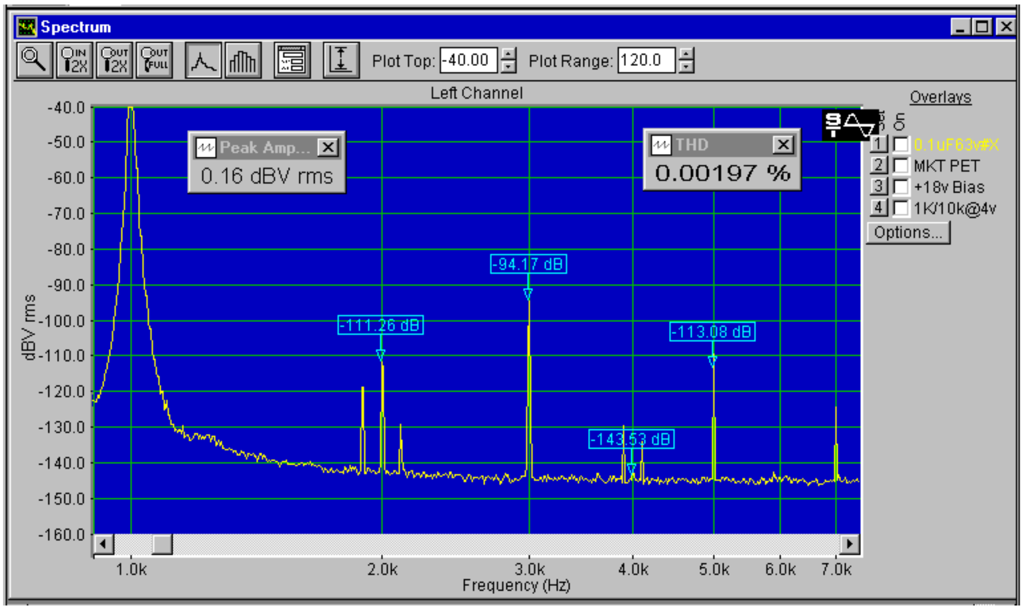

Fig 7) Measured with 18 volt DC bias the second harmonic increases by 20 dB to -111dB.

Harmonic distortion remains high regardless of test voltage. Dominated by the unusually high level of third harmonic it changes little.

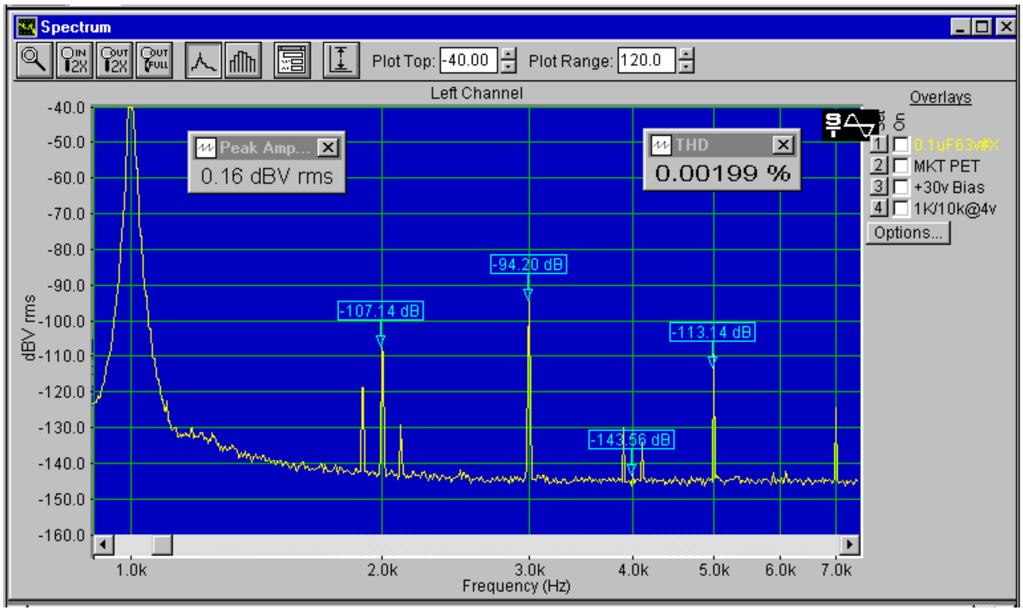

Fig 7B) Remeasured using 30 volt DC bias, second harmonic distortion increases to -107dB.

With tanδ 0.00371, this capacitor was dismantled to confirm it was stacked construction.

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

Box **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.

To produce exceptionally thin plastic films, the material is stretched almost to breaking along its length and across its width then 'fixed' by heating, changing the orientation of the long polymer chains. Initially 'tangled' these chains become straightened, re-oriented and cross-linked with consequent change in material characteristics, see Wima web site for details.

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 (PP) 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 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, so is not melted.

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 then provides the connection to the metallised electrodes.

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 (a few Ohms per square) 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 10 nF metallised PET capacitor might be rated for 30 v/µsec, foil and PET has a much higher current carrying ability, being rated as high as 1000 v/µsec. **End of Box.**

The 1 µF 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. Production of Bayer Makrofol Polycarbonate film having ceased, metallised Polycarbonate capacitors may disappear.

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

1 µF measurements.

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. **Ref.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 0.47 µF at 100 volt and 1.0 µF at 63 volt, were the maximum capacitances available in the case size.

I soldered together several pairs of 0.47 µF to produce near 1 µF 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 capacitor voltage ratings. Second harmonic for the 63 volt capacitors increased by +12.5 dB, the 100 volt capacitors by +7 dB, giving measured distortions of 0.00024% and 0.00011% respectively. see **Figs. 8 & 9**

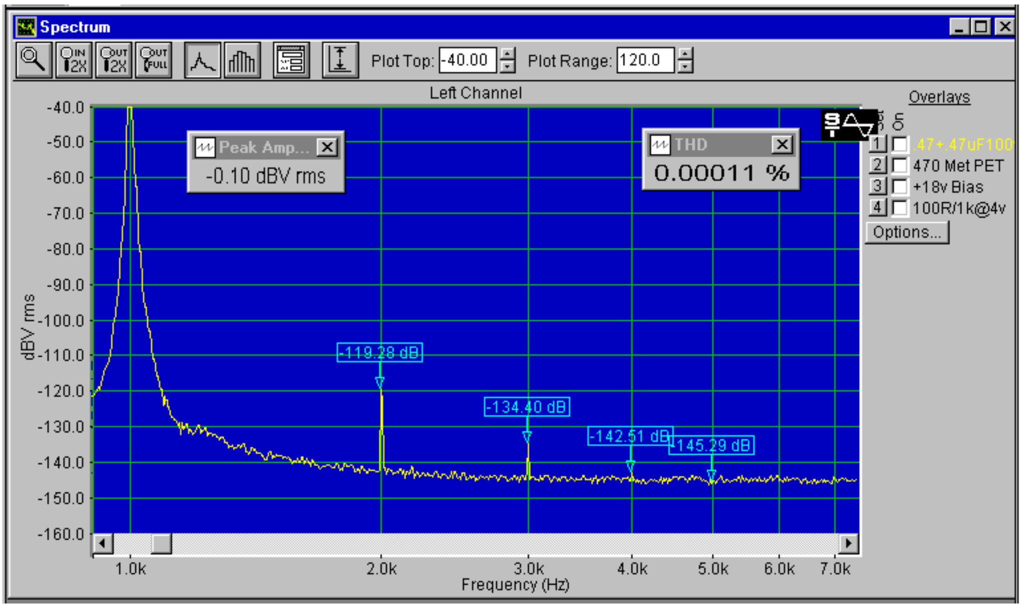

Fig 8) The first of two plots which explore the effect an increase in metallised PET film thickness might have on distortions. With no bias, distortion of this 100 volt capacitor measured 0.00006%, second harmonic -126.2 dB. With DC bias, second harmonic increased by 7 dB and distortion to 0.00011%

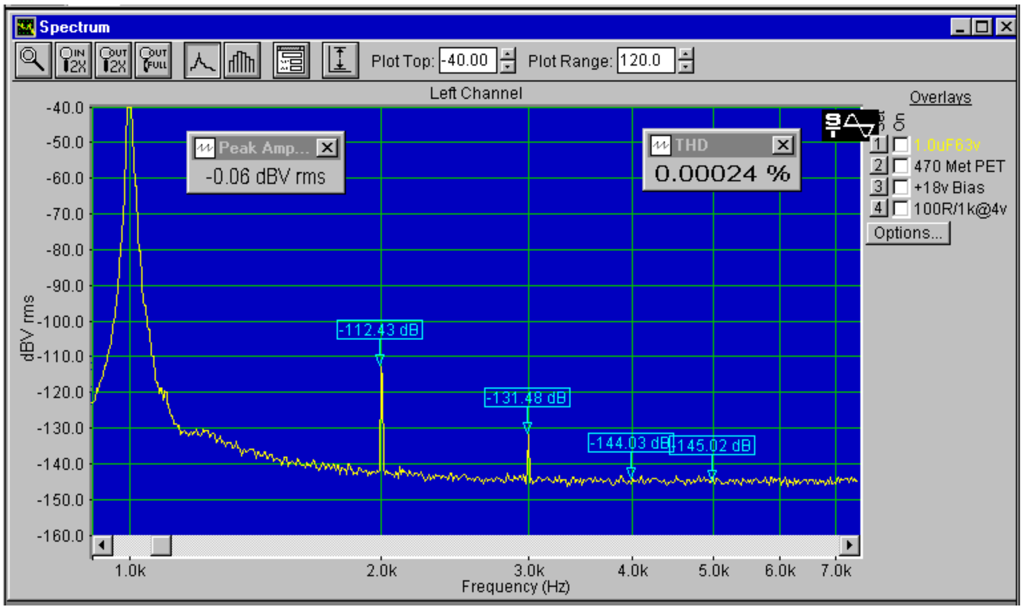

Fig 9) Distortion of the 63 volt capacitor, same make comparison with figure 8. With no bias, distortion measured just 0.00007% with second harmonic at -124.9 dB. With DC bias, second harmonic increased by 12.5 dB. At 0.00024% distortion is double that of the 100 volt capacitors.

These figures equate well with the expected differences in film thickness and confirmed the effect stress in volts/micron and dielectric absorption has on second harmonic distortion.

Some factor other than rated voltage, must account for Douglas's reported observation.

Further measurements on 1 µF 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, being repeated.

I also had 10 pieces 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 which 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 v magnetic leadwires. Not so, the lowest distortion, type 470, metallised PET capacitors tested, use magnetic leads, 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. **Ref.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 also used, having intermediate, mostly positive potentials. Possible 'Seebeck' effects should not be ignored.

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. see **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 0.1 µF to 1 µF 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, low distortion solution, is one possible ?

Polyphenylene Sulphide.
A much better but little used, slightly more expensive dielectric has been available for many years. **Ref.8** It is available metallised down to 1.2 microns and with a 'k' of 3, it provides capacitors slightly larger than metallised PET. **Ref.6**

It has many other benefits. Usable to 125°C, it provides a near flat temperature coefficient and tanδ slightly higher than metallised Polypropylene. It has a small dielectric absorption of 0.05%, considerably better than Polycarbonate and ten times better than PET.

Like Polycarbonate, Polystyrene and C0G ceramic, it provides superb long term capacitance stability, changing 0.3% maximum in 2 years.

It seems Polyphenylene Sulphide (PPS) should provide acceptable size, low distortion capacitors.

I used 0.1 µF 50 volt, 5 mm centres Evox Rifa SMR metallised PPS capacitors, in my tanδ meter assemblies. Measurements of 25 pieces I had left, displayed extremely low distortion. This stock was purchased from RS, who has since 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 5 mm lead spacing is 10 nF, with up to 1 µF at 63 volt in 10 mm centres and at 100 volt in 15 mm. The largest value, 3.3 µF at 63 volt, has 15 mm centres.

The 0.1 µF 100 volt SMR produced superb results with and without DC bias voltage. see **Fig. 10/10A/10B**

The 1 µF 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 capacitor made with much thicker film should be less sensitive. see **Fig. 11/11A/11B**

Both SMR types tested have small case size and 10 mm lead spacing.

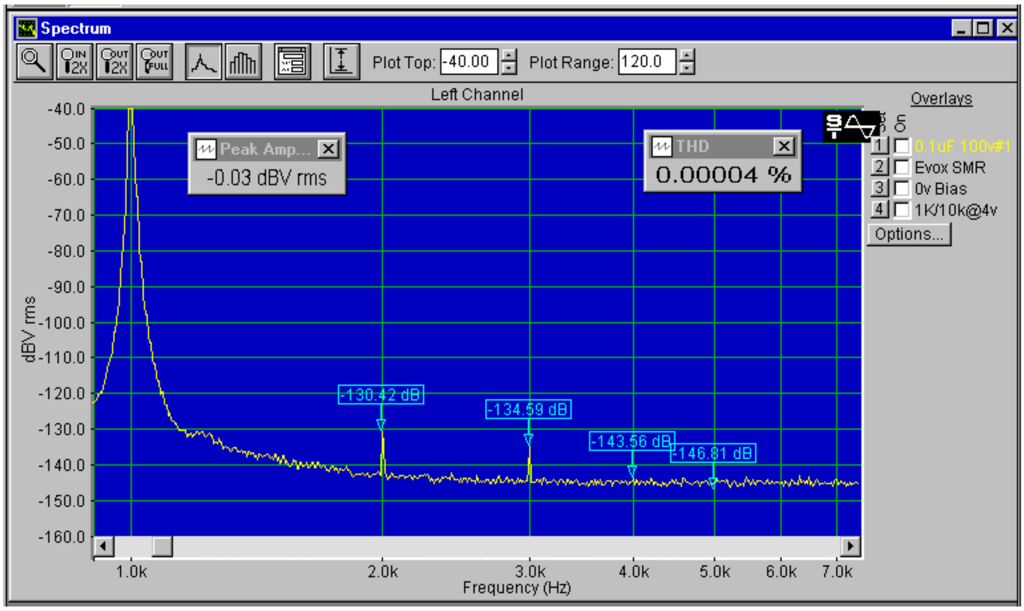

Fig 10A) All 0.1 µF 100 volt Evox Rifa SMR capacitors, made using metallised Polyphenylene Sulphide film, produced superb results when measured with or without DC bias voltage.

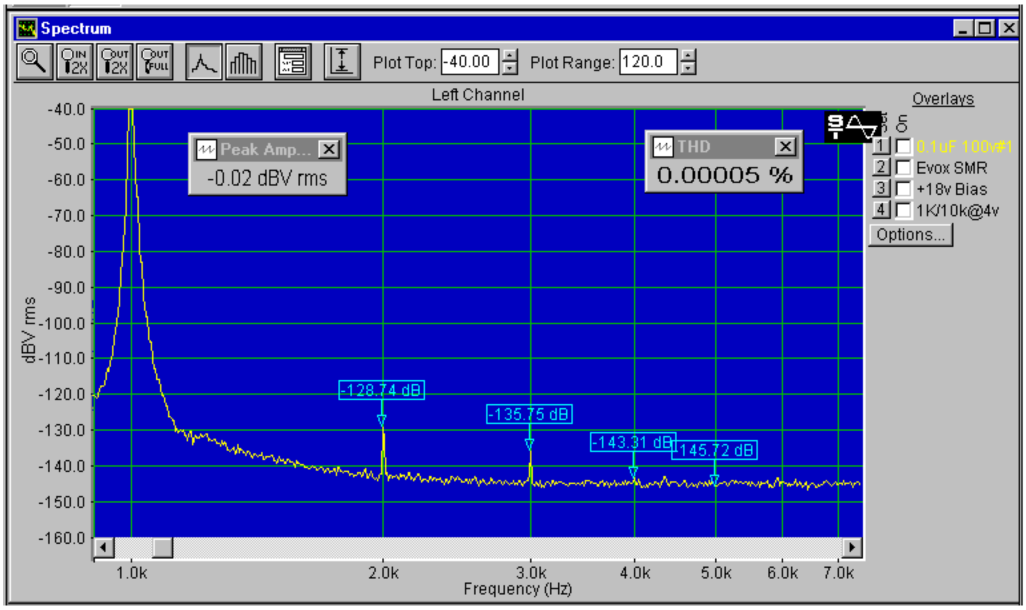

Fig 10) Second harmonic of the 0.1 µF 100 volt Evox Rifa SMR, increased by less than 2dB with 18volt DC bias.

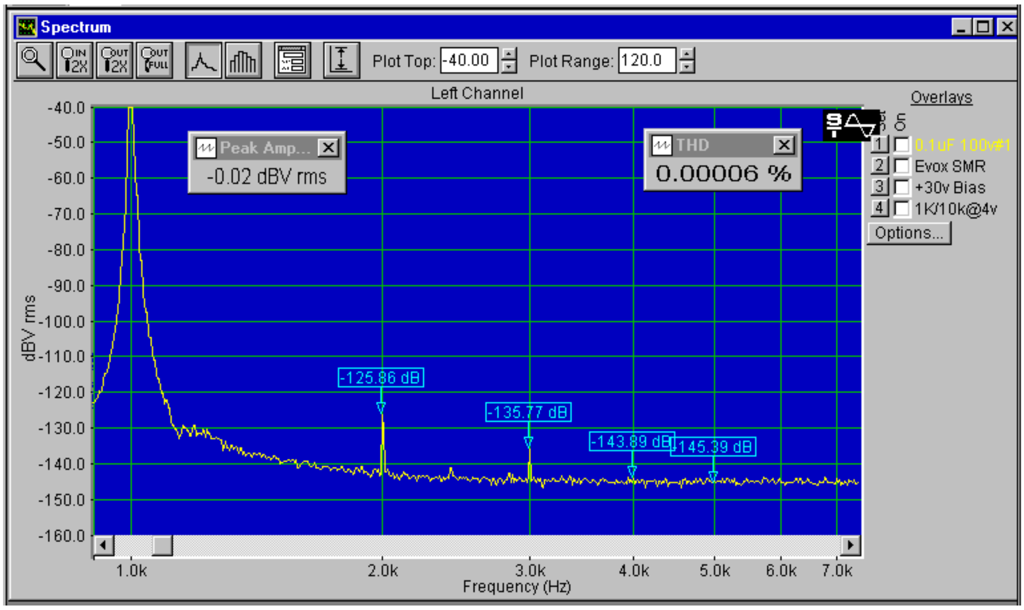

Fig 10B) Second harmonic of the 0.1 µF 100 volt Evox Rifa SMR increased to -125.8dB with 30 volt DC bias.

This small change, less than 5dB with 30 volt DC bias, directly results from the small DA of PPS film, which is considerably smaller than found for Polycarbonate .

Capacitors made using metallised Polyphenylene Sulphide are a little bigger and slightly more expensive than metallised PET types, but comparing distortions they do test consistently better. Altogether a superior capacitor for use in audio systems.

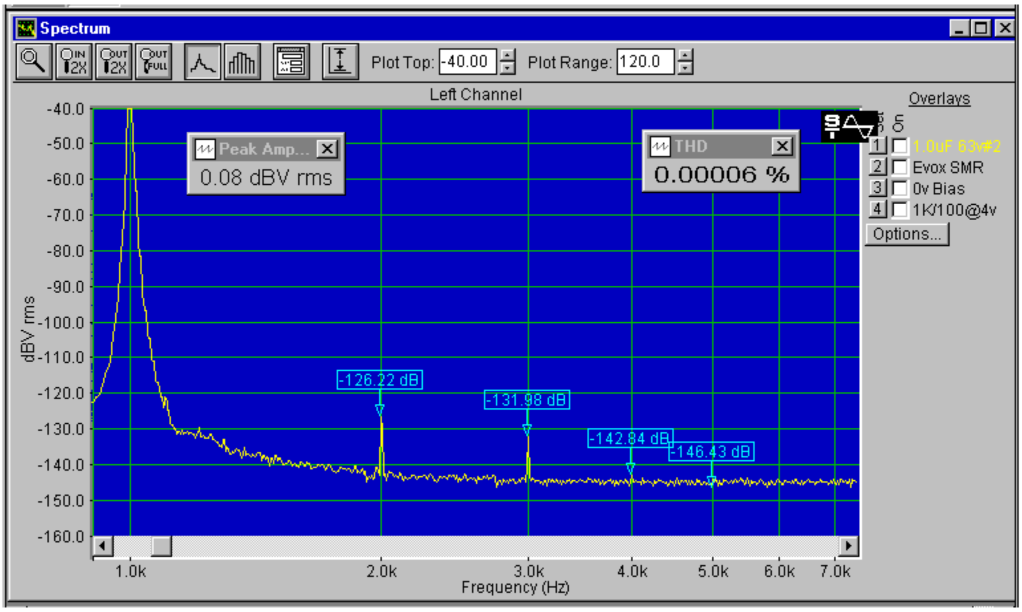

Fig 11A) The Evox SMR 1.0 µF 63 volt metallised Polyphenylene Sulphide film capacitor with 10mm lead centres, produced superb results unbiased and when biased to less than 10 volts.

With increasing bias however, second harmonic distortion does increase, but much less than for a similar voltage metallised PET capacitor.

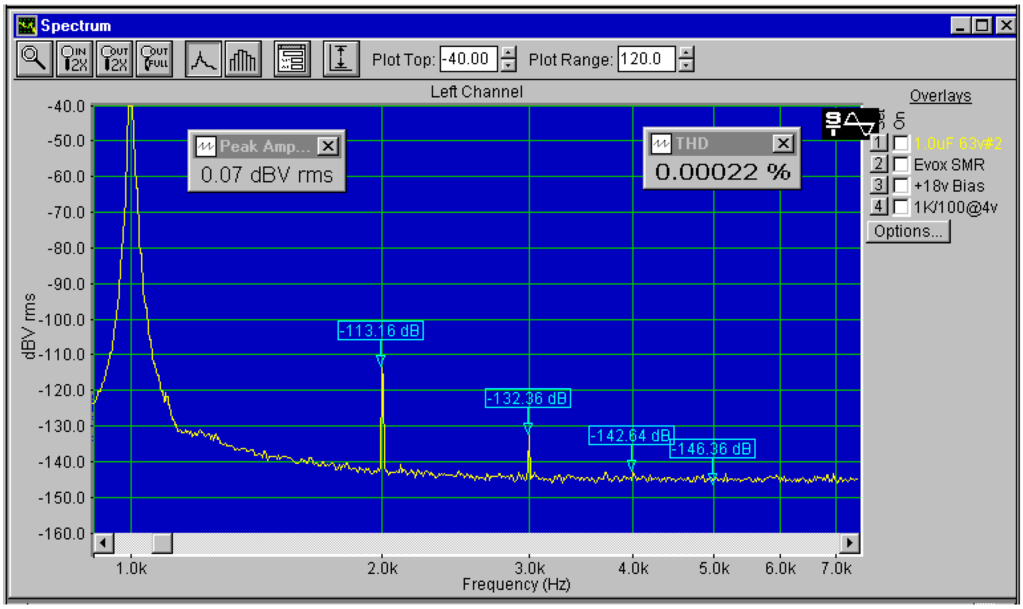

Fig 11) Second harmonic of the 1.0 µF 63 volt Evox Rifa SMR met PPS capacitor increased by 13dB to -113.2dB with 18volt DC bias. Almost 10dB better than the best met PET tested which increased by 22dB.

The larger 1µF 100 volt made with thicker film, has not been tested, but should be much less sensitive to DC bias voltage.

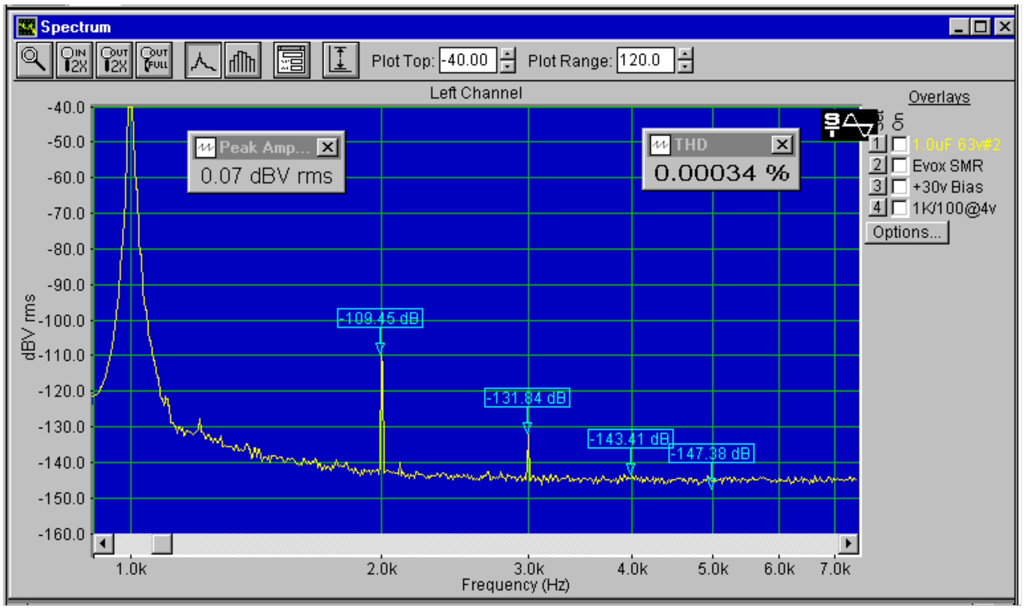

Fig 11B) Second harmonic of the 1.0 µF 63 volt Evox Rifa SMR met PPS capacitor has increased to -109.5dB with 30 volt DC bias.

This small change, less than 17dB with 30 volt DC bias, maintains nearly 10dB improvement over the best met PET tested. Made using very thin film, this improvement directly results from the smaller DA of PPS film, considerably better than Polycarbonate, very much better than met PET.

Bigger is best ?

Another new Farnell line is Polypropylene capacitors from Epcos (Siemens). The second harmonic of the 1µF 5% 250 volt B32653, 22 mm centres, changes little with DC bias up to 30 volts, distortion is then 0.00008%, a superb performance. **Fig. 12**

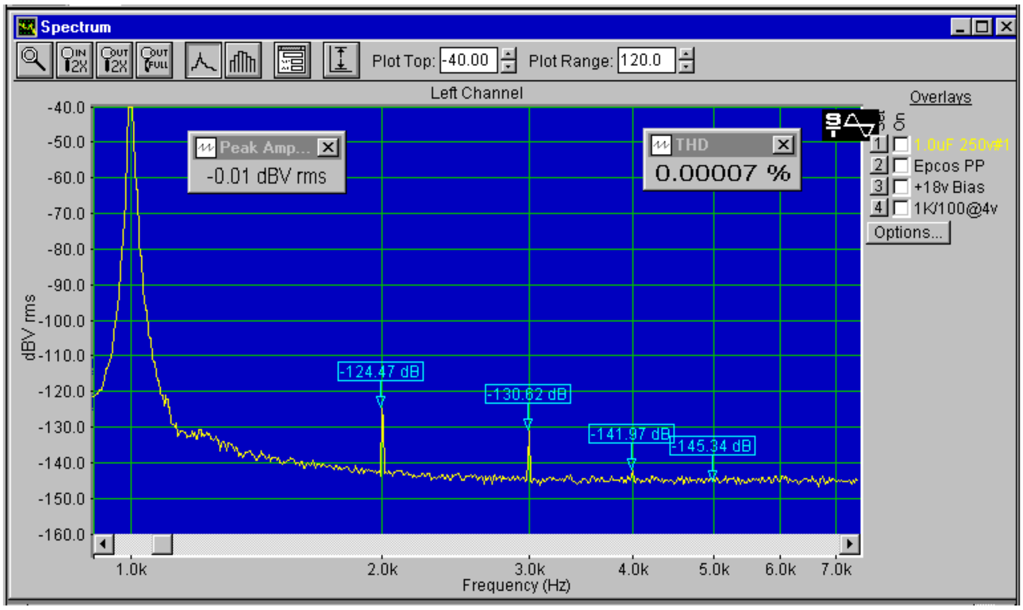

Fig 12) If you have room for a capacitor with 22mm lead spacing, this 1.0 µF 5% 250 volt B32653 capacitor from Epcos distorts less with 18 volts DC bias than did most capacitors when tested without DC bias.

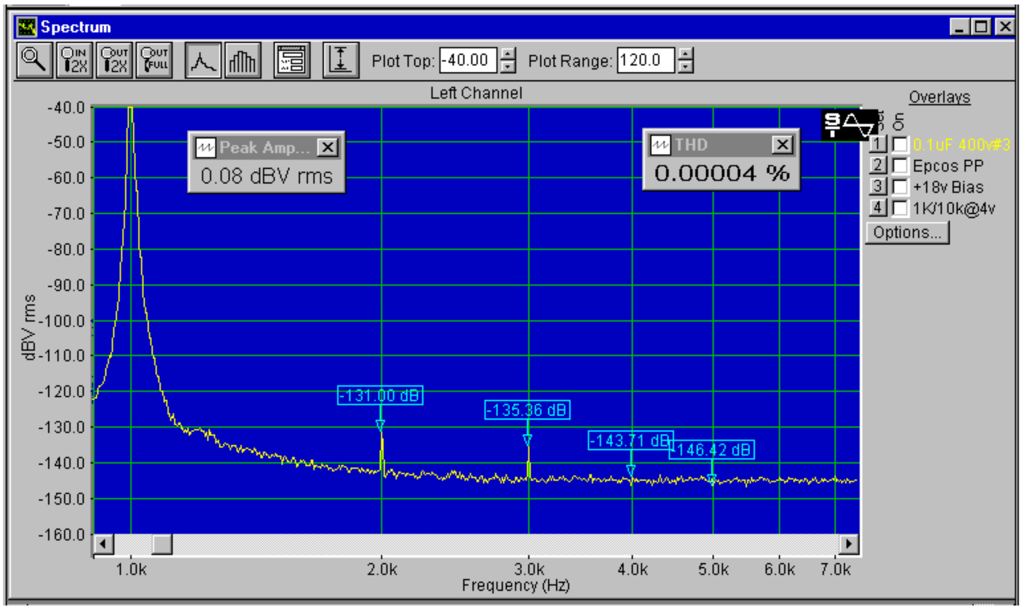

Fig. 13) As good as Polystyrene ? Distortions from this 0.1 µF 5% 400 volt 15 mm centres B32652, also from Epcos, measured just 0.00005% even tested with 30 volts DC bias.

Distortions from these 0.1µF and 1µF Epcos Polypropylene capacitors were not bettered by any similar sized capacitor I tested. With double the PCB footprint of the SMR types, however, they may not fit your available space.

No doubt these new lines will also 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 Electronics World amplifier design articles. **Ref.9**

Single tone 1 kHz amplifier harmonic distortion tests ignore distortions caused by the rising impedance of capacitors at low frequency. 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 1 µF, a metallised film or an electrolytic capacitor.

END.

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