Capacitor sound revisited

Distortion mechanisms behind the sound of Wound and Stacked Capacitors

Cyril Bateman

Introduction

Some days after joining Erie Electronics Great Yarmouth, the UK's largest maker of ceramic capacitors, as a Capacitor Process engineer, when I returned from the factory to our lab I heard a voice shout "Cyril, catch!" Without thinking I caught the object, only to immediately throw it away in disgust, having received a healthy electric shock. Thus began my initiation into Dielectric Absorption. This partially discharged, 1000V capacitor had recovered a very substantial charge.

So what is this dielectric absorption and does it affect high quality sound reproduction? A test method is described in the MIL STD, but perhaps more conveniently can be found on the Wima website[1], which describes a practical test method. Unlike all other capacitor tests, to measure dielectric absorption requires the capacitor initially be charged, partially discharged for a known time, then re-measured a known time later to establish any recovered charge voltage.

How does one measure Dielectric Absorption?

In practise this requires using a very low leakage switch together with a very high input impedance voltmeter and exceptionally consistent timing. For my tests I used a substantial, high grade ceramic, rotary switch, recovered from a Muirhead decade box, together with a 10,000 Mohm input impedance DVM and a stopwatch.

Since partial discharge followed by disconnecting one capacitor terminal is essential, this test only relates to circuits which operate in this manner, such as a sample and hold, also sometimes when using a charge amplifier. Therefore, Dielectric Absorption does not apply to a capacitor, which is charged to a stable DC voltage.
It certainly does not apply to capacitors used in traditional audio circuits, which maintain continuity of connection to both capacitor terminals and to any bias voltage used. Clearly however, should any inconsistency of connection or lack of stability of this bias voltage arise, then surprising results will be found, as the capacitor charges or discharges. This will be particularly relevant in case of over-

[1] http://www.wima.com/EN/absorption.htm

drive, clipping and similar conditions in audio circuitry. To avoid these conditions during my distortion measurements, all tests were performed using stabilised supplies for the distortion meter, together with Gel cell or dry cell batteries to ensure a constant capacitor bias test voltage.

To investigate any effect on harmonic distortion, with capacitors known to exhibit measurable dielectric absorption, in comparison with capacitors with no measurable dielectric absorption, I choose four capacitors previously measured and reported[2] [1]. All capacitors were of 100nF value and of similar case size.

Three were made using metallised Polyethylene Terephthalate (PET) dielectric, a well-known polar dielectric, while the fourth used metallised Polyphenylene Sulphide (PPS) dielectric, a non-polar dielectric which provides similar case sizes to these metallised PET samples.

Table 1 shows the test results. These capacitors were measured with 4V at 1kHz AC, together with 1V at 100Hz, to check for intermodulation. They were not polarised by any DC polarising or bias voltage.

Type	Dielectric	Polar /Non Polar	Style	Tanδ	D/A %	Voltco %	2nd Harmonic amplitude	3rd Harmonic amplitude	See measured results.
470	PET	Polar	Wound	0.00337	0.107	0.038	-133dB	-135dB	Fig. 1
MKS2	PET	Polar	Wound	0.00272	0.147	0.067	-128dB	-126dB	Fig. 2
MKT	PET	Polar	Stacked	0.00371	0.173	0.077	-130dB	-94dB	Fig. 3
SMR	PPS	Non Polar	Wound	0.00033	0.023	0.000	-130dB	-135dB	Fig. 4

Table 1. Harmonic distortion tests, 4V @ 1 kHz + 1V @ 100 Hz, no DC bias.

As will be explained later, the descriptions, polar and non-polar refer to how capacitor dielectrics respond to a polarising voltage; they do not infer that the capacitor in question would have a '+' and '-' terminal.

These test result numbers can be visualised more easily by examining the relevant distortion plots. For these and subsequent measurements, the 1kHz 4V test voltage was adjusted to read 0dB, so this peak appears on each plot at -40dB, having been attenuated by my 1kHz twin "T" notch filter. The actual harmonic values for distortion, 2kHz, 3kHz, 4kHz, 5kHz, are as shown, being the 2nd through 5th harmonics. The graphs in **figs 1, 2, 3 and 4** show the distortion with no DC bias applied.

2 All references to Capsound(s) or Capacitor Sound #4 refer to my original 2002 Electronics World articles, see [1].

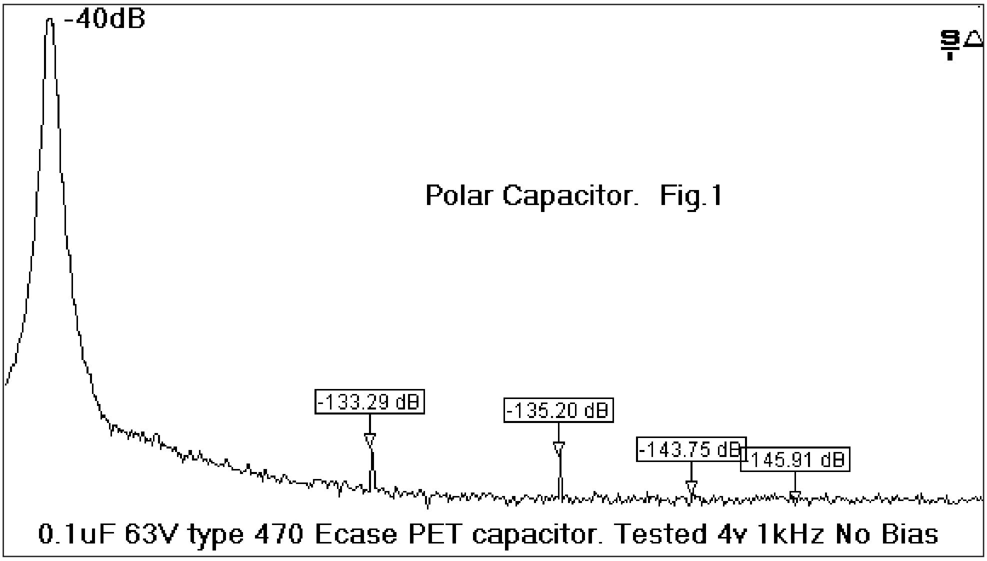

Figure 1. This polar dielectric capacitor was rated as exceptionally good in CapSounds 4.

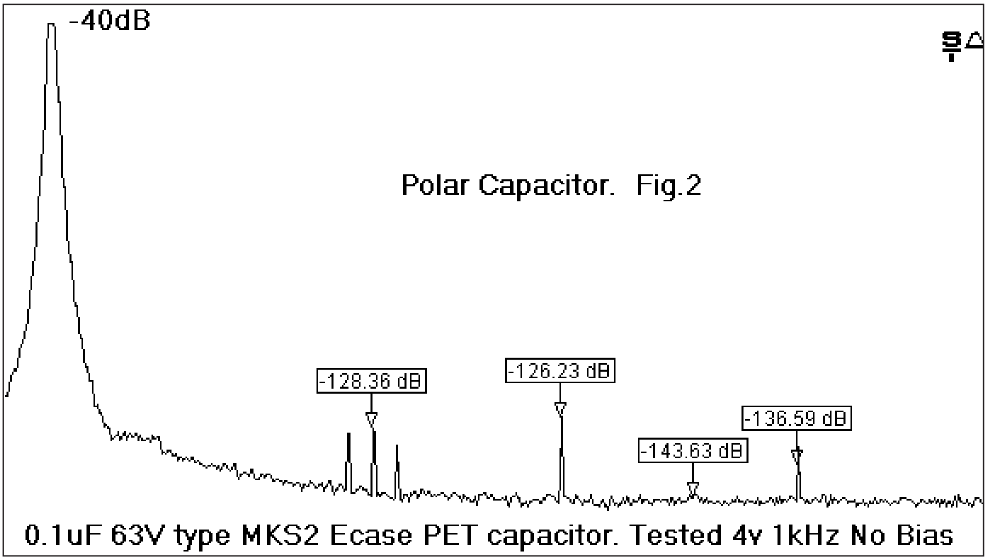

Figure 2. The PET used in this polar capacitor behaves slightly different from that used to make the Figure 1 capacitor, in that it shows a degree of intermodulation between the 1kHz test voltage and the much lower level 100 Hz signal, used for these tests.

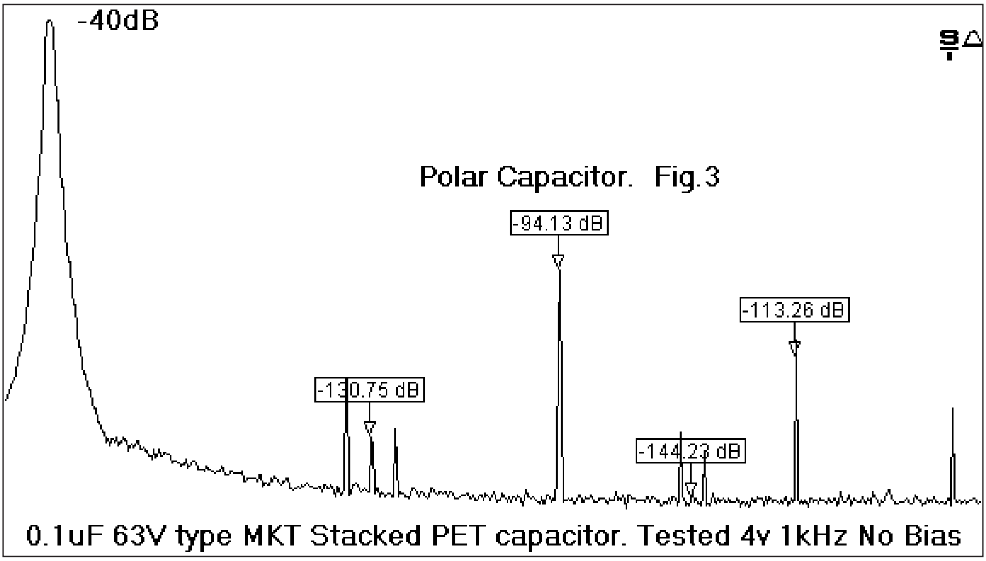

Figure 3. This MKT stacked film capacitor test result is typical of all stacked film capacitors measured, whether potted into an E case or simply left bare. Notice the much increased intermodulation, we now also measure a notable level of third and fifth harmonics.

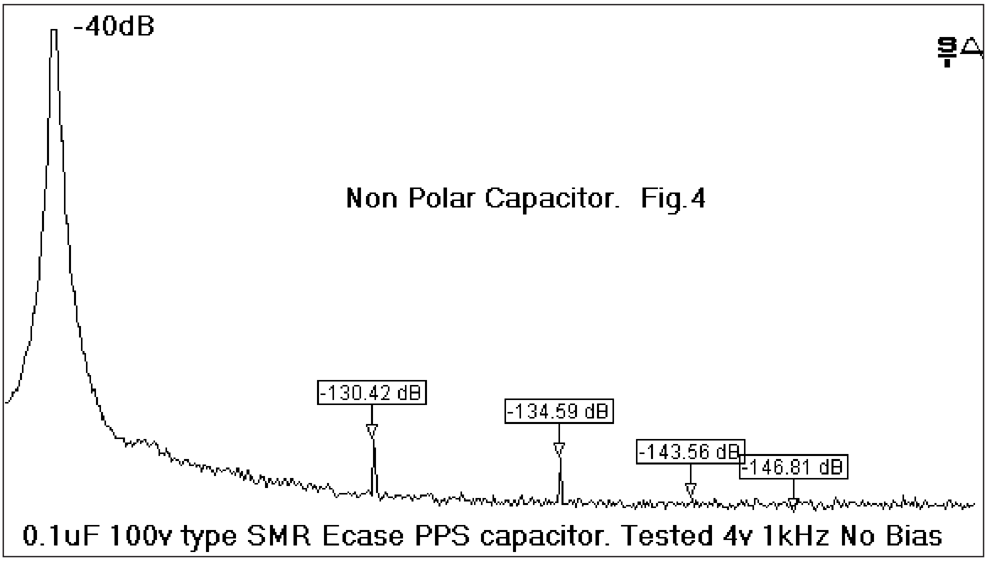

Figure 4. This excellent non-polar capacitor, is better than the 1ppm limit of my equipment.

The distortion plots for these E-cased capacitors, figs 1 through 4, measured with no DC bias or polarising voltage, look pretty good. Unfortunately we can already observe the unusually high third harmonic distortion, which I have found is usual for all stacked film capacitors, whether bare, or in an E-case. Let us now explore how a DC polarising, or bias voltage affects capacitor distortion, for these four capacitors. For capacitors used to DC block between audio equipment stages, it is usual to use such a bias voltage. The resultant graphs are shown in **figs 5, 6, 7 and 8** with 18V DC bias applied.

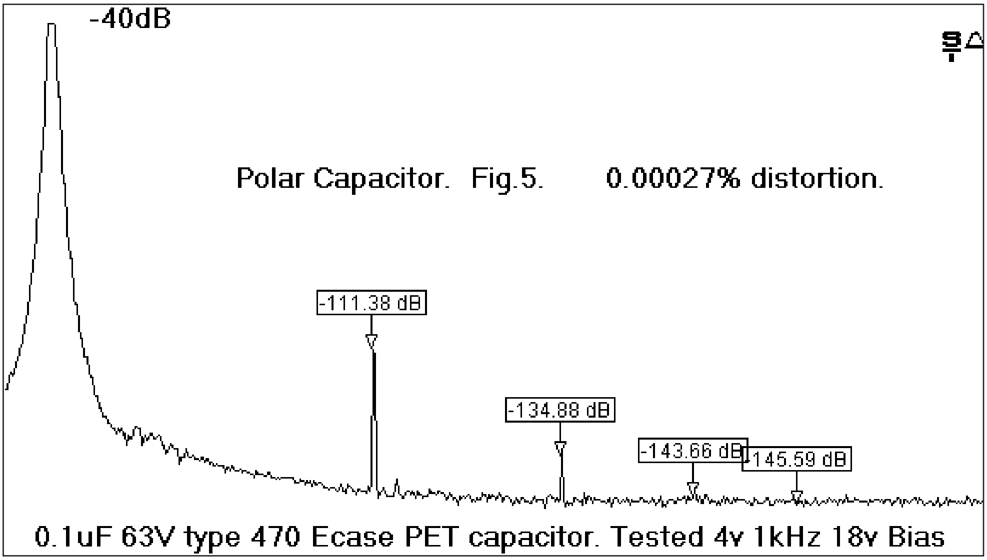

Figure 5. The figure 1 capacitor re-tested, but now with an 18v DC bias voltage.

Using a polar, metallised PET capacitor with 18v DC bias voltage, we now find the capacitor has manufactured a level of second harmonic distortion, which increases with increase in bias voltage. However, this is still quite a good test result.

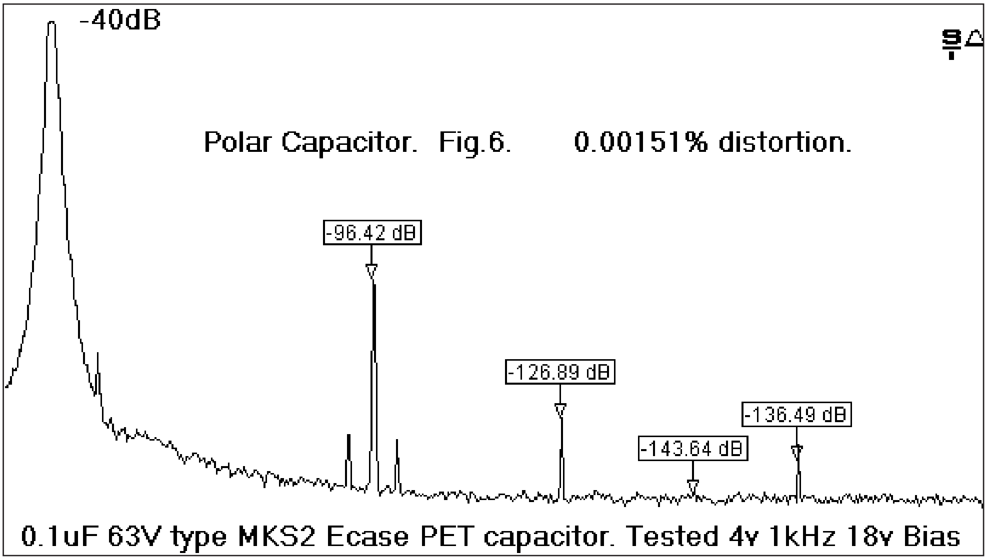

Figure 6. As seen in figure 2, the particular metallised PET film used, again produces a poorer result.

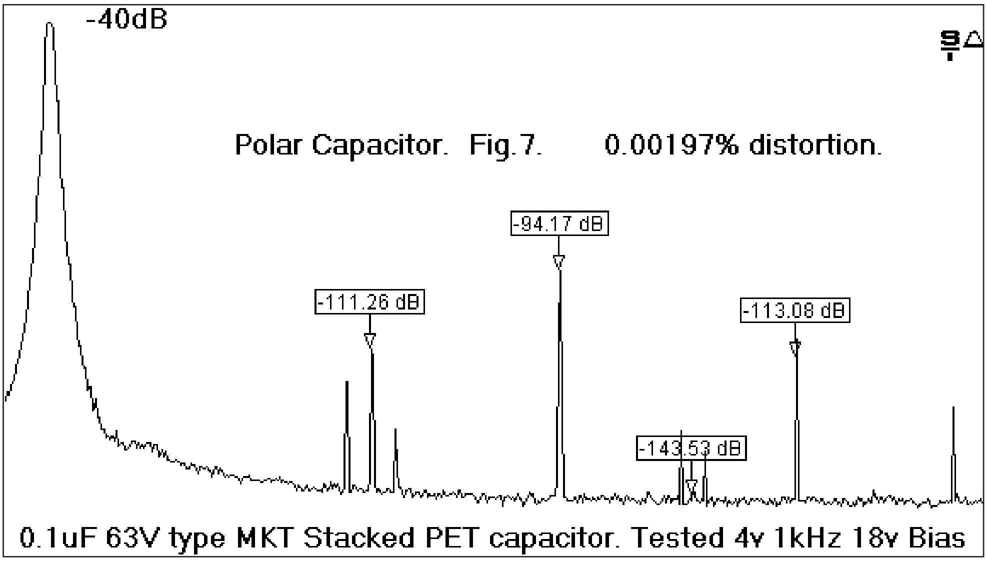

Figure 7. As expected the second harmonic distortion as well as the intermodulation level has increased with the application of a DC bias voltage. However the odd harmonics are little changed.

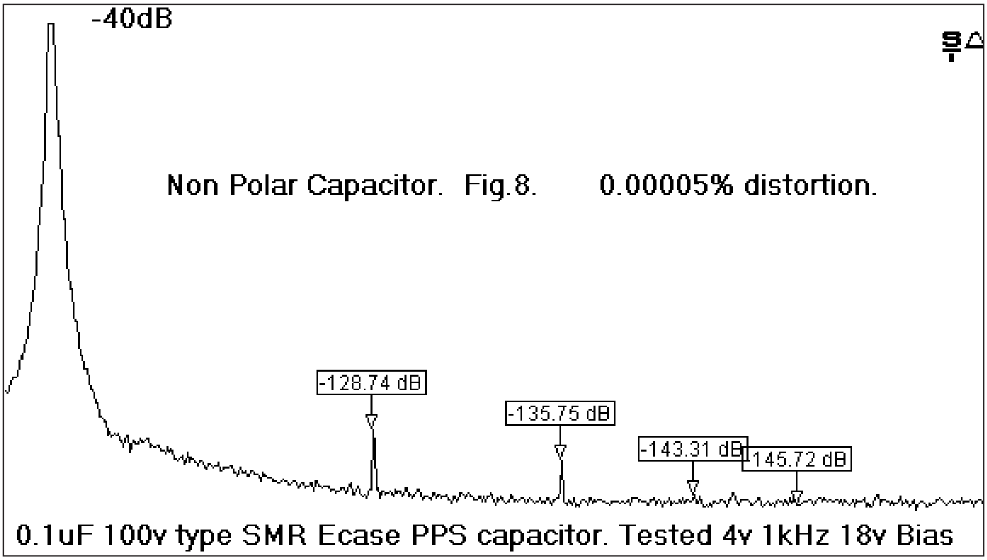

Figure 8. With this application of 18v DC Bias voltage, distortion from this non-polar capacitor remains smaller than can be accurately measured, using my -120 dB, 1ppm capable equipment.

These last two measurements clearly illustrate just why I have always recommended using a non-polar capacitor dielectric such as this SMR, metallised Polyphenylene Sulphide dielectric. It offers every advantage over Metallised PET, except for a very small size and cost premium. Other common non-polar dielectrics are Metallised Polypropylene, Polystyrene and COG ceramic.

It is clear from the above metallised PET plots that dielectric absorption has no special effect on harmonic distortion. We see only the usual harmonic series and the observed intermodulation. However choosing very small, low voltage capacitors, made using very thin metallised PET dielectric, ensures larger distortions for a traditional wound capacitor but dramatically larger distortions, especially the third, fifth and higher harmonics, for a stacked metallised PET film capacitor.

Second and Third harmonic distortion measuring equipment, as used for these tests.

A few words about the distortion measurement equipment I used. It comprises the low distortion oscillator, the schematic and PCB layout of which were detailed in Electronics World July 2002. It attained rather better than my target 1ppm distortion. The low distortion 1kHz notch filter which reduces the 1kHz test signal by some 60 dB to facilitate measurement of the capacitor harmonics, places the -40dB test level at the top of the spectral analysis screen. My very low distortion output buffer amplifier can drive undistorted, more than seven volts at 1kHz into a 100 Ohm 1uF capacitor test combination. Finally a very low distortion, DC blocking, low loss, buffer network, which allows the application of a DC bias voltage to the test capacitor, completes this system.

The photographs in my Electronics World, Capacitor Sound 2 article, September 2002, clearly show my use of non-polar dielectric film capacitors throughout in these assemblies.

These modules comprised my original test method, which sold to many universities and readers, but after many thousands of capacitor distortion plots, I tired of the need to use the soundcard FFT software method to display the result. After some thought I decided to design a second and third harmonic selective receiver board, able to directly display second and third harmonic distortion levels, on two seven segment displays, see **fig. 9**.

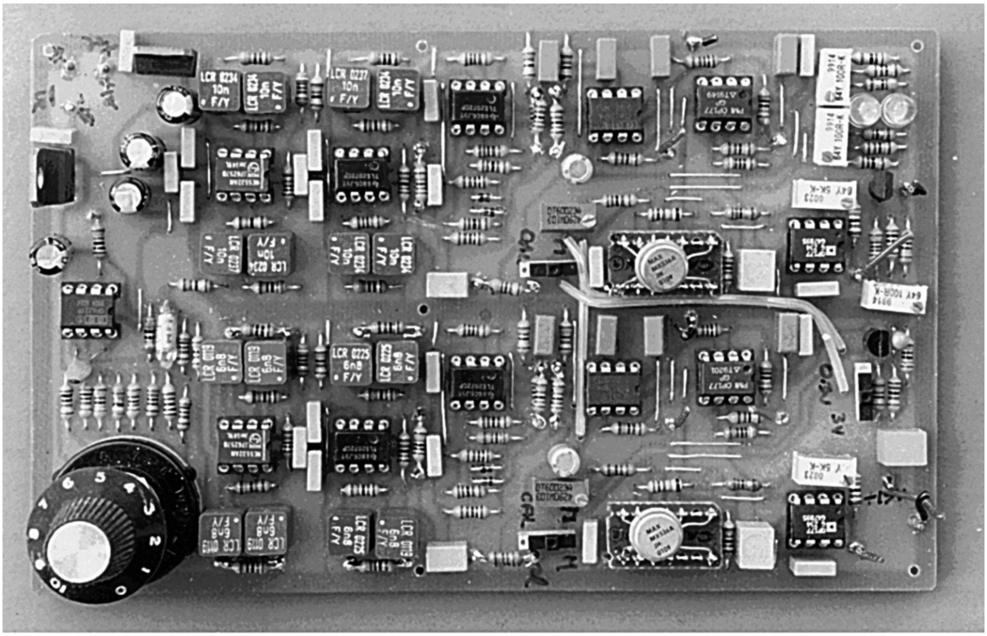

Figure 9. My second and third harmonic receiver, designed to accurately measure harmonic levels and display these values using two seven segment LCD displays.

Second and third harmonic distortion levels are measured using two true RMS AD536 modules, as described in Electronics World July 2003. Because these seven segment displays do take time to settle, to facilitate observing any dielectric absorption effects, I added two much faster output level readouts, showing distortion in 3 dB steps. Based on two LM3915 displays driving two chains of LEDs, these show the distortion levels for the second and third harmonics.

These two 3 dB/step LED columns reveal just how distortions change with the application of a bias voltage as the test capacitor charges or discharges, but all harmonics become stable once the test capacitor has fully charged. During charge or discharge, these second and third harmonic LED columns chase up and down, stabilising only when our test capacitor is fully charged or fully discharged. The two seven segment displays then show the actual measured second and third harmonic distortion levels to the nearest 0.1dB step.

The above, packaged into a small low cost equipment case, was described in Electronics World July 2003. This equipment provides much better, detailed, analysis of capacitor behaviour than relying on the traditional simple distortion measurement. Any rapidly changing distortion, caused by dielectric absorption, shows in the height of the two 3dB LED display chains, long before the two seven segment displays settle sufficient to allow a reading. **See fig. 10**.

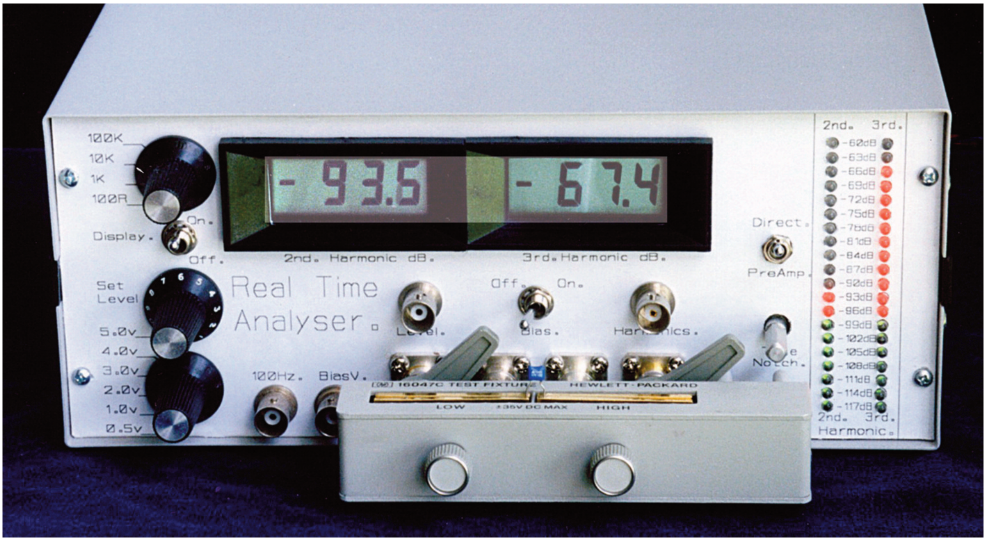

Figure 10. The equipment as used for these tests. A test jig, which maintains true four terminal connection from capacitor to measurement circuit, is essential when performing such large dynamic range measurements.

We have seen in figs. 1 through fig. 4 that when biased with an AC voltage much smaller than the capacitor rated voltage, measurable distortion products can be generated, in some but not all capacitors. In figs. 5 through fig. 8 we also find from testing with a small AC voltage together with a DC polarising voltage, again smaller than the capacitors rated voltage, high levels of second harmonic distortion can be generated in many capacitors..

So how can we select a capacitor construction to minimise these effects?

Even a non-polar, balanced molecular structure, such as a Polypropylene capacitor, subjected to a polarising voltage can exhibit a small level of dielectric absorption, as also did our SMR capacitor of figure 4, caused by part of its electron cloud becoming attracted out of its normal position, by the attractive effect of this polarising voltage.

What's a non-polar dielectric? I should clarify my use of polar and non-polar dielectric, which should not be confused with Aluminium Electrolytic, often also called polar and non-polar. With the electrolytic capacitors we are simply describing whether they need a unipolar bias voltage or can be used with either polarity of bias.

With plastic film capacitors these terms describe a quite different, molecular level, dielectric behaviour. A non-polar dielectric has a simple, short, molecular structure in which the nucleus is surrounded by its electron cloud. A polar dielectric is a long and unbalanced molecule so has a polar vector caused by an excess of unbalanced electrons. Perhaps the most common, simple example, is water, or H_2O. Common plastic film capacitor dielectrics have an exceptionally long molecular chain, especially so for metallised PET. The polar moment caused by this unbalanced molecular structure results in the dielectric absorption, as well as the level of second harmonic distortion I measured.

Capacitor catalogues offer a variety of dielectric choices/sizes according to the dielectric used in their manufacture. Inevitably the lowest quality, worst distortion capacitors, prove the most popular, simply because they provide the smallest possible size and at the lowest cost.

Non polar capacitor dielectric.

Polypropylene (PP) whether metallised or with metal foil electrodes, provides the lowest possible distortion for two reasons. First it is only available in film sizes much thicker than is metallised PET, typically 2.5 micron and above, effectively limiting the "volts per mil" stress which can be applied. Second it provides the lowest dielectric absorption of any capacitor dielectric. A Polypropylene capacitor, value for value, will be bigger than with other dielectrics. For these reasons, I selected a 250 V KP376 1uF foil and polypropylene capacitor for long term use as my distortion reference test capacitor.

Polyphenylene Sulphide, (PPS) provides exceptionally low distortion in a much smaller case size, little larger than an equivalent metallised PET capacitor, due to its increased permittivity and the PPS being available as a very thin film. A PPS metallised capacitor provides the best, low distortion, small case size capacitor choice in practise.

To examine the effect these variations have on distortion, we need to look more closely into the nature both of conductors and insulators. Clearly any capacitor needs both. The very thin metallised coating of metallised capacitor styles, or the thin metal foils of the foil and film types, are excellent, very low resistance conductors.

In contrast the dielectrics used, of necessity, are almost perfect insulators. One of the most common quality guidelines used by capacitor engineers is to expect every film or ceramic capacitor to exhibit a typical insulation resistance of around 10k Megohms.

As engineers we accept that all metals have an extremely low resistance, able to conduct current, but maybe are rather less happy as to why plastic film and ceramic capacitor dielectrics exhibit such an exceptionally high resistance to any direct current flow, yet when connected in circuit, capacitors can pass current.

For this to happen our dielectric must first become polarised.

The word insulator derives from the Greek word for islands, suggesting that within the dielectric, each molecule acts as if marooned on an island, complete with its nucleus and electron cloud. Unlike a metal, a dielectric's electrons are constrained from breaking away from its nucleus, so cannot easily pass current. Some writers have likened this effect to the dielectric electron being like a dog, restrained by a chain, able to move around within limits, but not able to escape.

One web site I strongly recommend, www.doitpoms.ac.uk, is part of the University of Cambridge. In 2000 they set up, together with an amalgamation of other major UK universities, a joint venture for "dissemination of IT for the Promotion of Materials Science". The website provides an array of downloadable, self-teaching and learning packages, including videos and downloadable interactive modules. These cover all aspects of insulators, which helps our understanding.

"A dielectric supports charge by acquiring a polarisation in an electric field, whereby one surface develops a net positive charge while the opposite surface develops a net negative charge. This is made possible by the presence of electric dipoles – two opposite charges separated by a certain distance – on a microscopic scale."

A Google search for "doitpoms dielectrics printall" should take you straight to their most relevant web page, alternately go to http://www.doitpoms.ac.uk/tlplib/dielectrics/printall.php .

The non-polar dielectrics are comprised of compact molecules, whereas polar dielectrics have a much longer molecular chain, increasing the spacing of the nucleus from its electron cloud and a significant increase of polar moment. For instance Polyethylene Terephthalate (PET) is an exceptionally long chain molecule with a large polar moment which results in its large dielectric absorption, accounting for the measured distortions. However even the very best non-polar dielectric molecules must also have some small, finite, physical size, resulting in a small polar moment, explaining the much smaller distortion and dielectric absorption I measured in my table 1 test results.

Naturally any increase in applied voltage, both of the AC test drive signals and any DC polarising voltage for the dielectric, increases these effects, so as often mentioned in my original Capacitor Sounds articles, it is the *applied volts per mil of dielectric thickness*, which determines harmonic distortion levels, for a particular capacitor.

Let’s now look at the more popular Polar Capacitor Dielectrics

Polyethylene Terephalate is one of the oldest high polymers, being synthesised from Ethylene Glycol and Terephalic acid, to produce a long chain, polymer molecule. Originally produced as a thread to make clothing, it was later refined to make the now familiar clear plastic film. While metallised PET is a generic name for the dielectric, it can be prepared using many different methods, each producing slightly different end results. This exceptionally thin film, typically less than 1micron thick in the 63V capacitor, commences as a liquid resin, extruded to make a thin walled tube, but much too thick for capacitor manufacture. This tube’s thickness can then be significantly reduced by inflating with hot air, rather as we would blow up a balloon. It can then be heated and stretched, both length wise and cross wise, either in turn or bi-axially in one operation. This stresses the PET molecules, causing molecular cross linking, resulting in an exceptionally strong, extremely thin material, eminently suited for use in high speed capacitor winding machines.

When reduced to the desired thickness, the film is finally “set” at high temperature, resulting in even more crosslinking, together with a degree of crystallisation, which permanently sets the film to this thickness. Such very thin PET has been likened to being “as strong as steel,” thickness for thickness.

To see how this relates to our measured distortions with no DC bias, see again figures 1 through 4. Three of these capacitors included significant levels of dielectric absorption, yet their distortion plots clearly show that Dielectric Absorption has no special effect. All three of these wound, metallised PET capacitors, when stressed with 4 V 1kHz, measured only second and higher, even, simple harmonic distortions, smaller than the 1PPM or -120dB measurement ability of my instrument.

Stacked metallised PET capacitors, produce quite different, third, fifth and odd harmonics

The MKT stacked, metallised PET capacitor however also included, easily measured, consistent, high levels of third, fifth and higher harmonics; these levels were not found in the wound style capacitors, regardless of DC bias voltage. These stacked types were also prone to intermodulation, when tested as I did, using the stimulus set to a value at 1kHz together with a lesser value stimulus at 100 Hz. In practise in an amplifier with music signals, we must expect such a capacitor to be subjected to a great many stimuli, resulting in significant intermodulation and harmonic distortions.

So far, we have seen that:

- All *non-polar* dielectric capacitors I tested, with and without DC bias, produced no measurable harmonics or intermodulation, within the 1PPM or -120dB measurement capacity of my equipment;
- Application of DC bias voltage, see figures 5 through 8, to a capacitor with a polar dielectric, results in measurable increases of 2nd harmonic distortion, which increase further, as DC bias is increased;
- Regardless of DC bias, odd harmonics for the “stacked” film capacitors differed significantly and were independent of DC bias, being measurable using quite modest harmonic distortion instruments, even my ancient HP 331A distortion meter.

Clearly high levels of 3rd and odd harmonics, with or without DC bias voltage, result from the relatively new "stacked" film assembly construction, rather than from any effect of a Polar Moment, or Dielectric Absorption.

Having clarified that Dielectric Absorption has no special effects on our conventional simple harmonic distortion measurements, we can now proceed to test our new purchased capacitors.

New tests

Early last year, studying current data sheets, I found two new potential problems. Some of the better capacitors I had tested in 2003 were now listed as having a slightly different case size, so something had clearly changed. Second I noted a vast number of Far Eastern makes were now being offered, usually described as being of "stacked" construction.

Stacked metallised PET film capacitors present two benefits to the maker. To wind traditional wound or flattened obround capacitors, each capacitor must be wound, flattened, then jigged for end spraying individually, and this requires a big investment in many individual high speed winding machines and significant labour costs.

Stacked metallised film capacitors are much less costly to make, since large quantities of these capacitor elements are wound, end sprayed then cut to size, while they remain attached to their original large diameter winding wheel. A thousand capacitors can be quickly produced using only a single winder with one or two operators, allowing almost anyone to start manufacture, for little money.

Some makers now offer larger value, stacked film capacitors. 10uF is available, so could replace many Aluminium Electrolytic types. I've not measured any stacked film capacitors larger than 1uF, but apart from an increased 3rd and higher order odd harmonics, would expect to find rather less total distortion than for many polar aluminium electrolytic types.

Wound capacitor construction describes the most common, traditional method of assembling metallised film capacitors. A small diameter, high speed rotating split spindle is used to quickly wind up a roll of the two metallised foils needed for the low voltage metallised film capacitors usually used. This tubular winding is finished by "scoop" hot metal spray onto both ends of each wound roll, to make electrical contact with both metallised electrodes and produce the common round, tubular form, capacitor. To save PCB area, many makers wind up rolls of metallised film, as above, except now using a much larger diameter spindle. The finished winding is then compressed and flattened while heated, to produce the common obround, oval shaped format.
The winding can then either be resin sealed into an "E" case, or dipped in resin to make the obround capacitor style often used for PCB assemblies.

Both the above winding methods, describe the traditional, wound capacitor construction, as used for many years, in which two continuous lengths of metallised film dielectric are interwound to comprise a wound film capacitor.

Before discussing stacked film capacitors, first some more history

The stacked construction was invented in the mid-sixties, around the time I joined Erie. It was a screen printing process, used to make the very first monobloc multilayer ceramic capacitor contract for IBM. Rolls of plastic film were drawn through liquid ceramic slip, which after drying left a thin layer of unfired, flexible ceramic which could be electroded by screen printing, then stacked and fired, into a solid block, to make the original multilayer ceramic capacitors. Modern multilayer ceramic capacitors however, are usually made using the "wet" screen printing process. Three years later, Erie purchased the A H Hunts factories, maker of the old L45 impregnated foil and paper capacitor still loved by many audio enthusiasts. By that time I had developed a new "polarised" ceramic decoupling capacitor, intended to size reduce the very first midget transistor radios. I found myself assigned to take charge as chief designer, for the Aluminium Electrolytic capacitor ranges Hunts made at their New Addington, near Croydon and at their Wrexham, North Wales factories. One year later, my small Gt. Yarmouth team had developed, QA tested and displayed at the RECMF exhibition, the first electrolytic capacitor ranges designed to meet the new reduced sizes, with the rationalised capacitance and voltage ranges then needed to satisfy the new UK metrication laws, beating the competition by more than a year. These new size reduced capacitors were exceptionally popular, transforming a previous loss making factory into one making a good profit.

About that time, Siemens offered to sell licences for their stacked film capacitor design, so that others could replicate. Erie undertook such a development. I was not involved, but working in the adjacent laboratory had to pass by this development team, to enter and leave my desk. Prototype equipment was built, but Erie subsequently canned the project. By that time the new large screen colour TVs, which required much more powerful capacitors for their EHT and scanning systems than previous, were being developed, causing a great many capacitor problems, even several fires and some deaths. Equipped with a car, now as Senior Applications Engineer, I was asked to assist our customer sales engineers and our factories, to solve these problems. Life became very busy, I needed to travel most days to discuss problems/solutions with customer's development engineers or at our factories, most being located 150 to 200 miles from Gt. Yarmouth.

Third Harmonic Distortion Test

With the Ericsson designed CLT1 Component Linearity Test Equipment, capacitor distortions suddenly became a hot topic. The Erie UK company purchased two instruments, one for our resistor engineering department, the second was initially given me to evaluate. I tested several hundred capacitors of all types, but quickly decided, apart from the high-K ceramic styles, none of our capacitors exhibited significant third harmonic and this equipment could not measure second harmonic. No customer used high-K ceramic capacitors in audio or TV equipment, so I gave up and passed the kit onto other engineers. Three years later, I came across both units in a waste skip, waiting to be sold on to a used test instrument dealer.

As I was preparing this article, some writers resurrected the "capacitor third harmonic is dominant" case. Concerned, I decided to recheck my earlier work. Using the soundcard spectrum analyser takes time while the software completes the required averages, so watching the two 20 LED display columns and the two meters, I measured every capacitor I possessed in an attempt to find some which, with no DC bias, exhibited this claimed large 3rd harmonic with smaller second harmonic. These capacitors were all of known construction; some were quite old, overmakes from customer specials. This included the very first, wound, metallised polypropylene film capacitors, which were BS approved for use on 50Hz domestic electric supply both 230 and 400volts AC. Several were series wound, with double and quadruple winds, others were used in very high voltage colour TV EHT generators as well as many samples originally specially designed for use in very high quality, high power, audio amplifier and loudspeaker systems.

For completeness, I also measured many air cored inductors, commercial resistors and the multi-gang air spaced tuning capacitor from my Hewlett Packard 331A distortion meter. The only instances of significant third harmonic distortion I found was in carbon composition resistors, high K ceramic capacitors, especially the US BX multilayers and stacked metallised PET film capacitors. Satisfied that within the test voltage levels applicable to audio equipment coupling capacitors, it was indeed the second harmonic which was dominant in conventional wound film capacitors, I could now proceed to examine the 70 capacitors, specially purchased, for this new paper.

Purchased New Test Capacitor listing

Since my Electronics World articles, the capacitor industry has changed significantly, not only because of the new Far East threats, but more significant because several old, well respected makers have been taken over, merging product names sufficient to confuse. Many others are now expected to be relocated to the Far East.

I tried hard to purchase a physically small, non-polar dielectric, 1uF capacitor, but failed. Evox Rifa OY a long established and highly respected maker, had been purchased by Kemet. As a result I was not able to source a small quantity of new PPS 1uF capacitors in the UK, however they may now be available in the US. For convenience I usually purchase my capacitors from Farnell Electronics UK.

The type 470 capacitors which had performed so well for my Electronics World tests now appeared to have been size reduced and renamed, so 10 each of 1uF also 0.1uF were purchased; they are listed as BFC247076 .

I similarly purchased 10 pcs each of 0.1uF and 1.0uF of the Wima MKS2 63v, to check current quality. Finally for the repeat tests, I ordered 10 each of 0.1uF and 1.0uF of the MKT stacked film capacitors, listed as B32560J style at 100v.

To complete the list I noticed some newer, interesting, obround, metallised PET dipped designs, so purchased just 5 pcs each of Panasonic ECQE in 0.1uF and 1uF at 250v, also BFC2368 style, again in 0.1uF and 1uF values at 100v.

Tests Performed

Each of these new purchases were carefully measured for voltage coefficient and tanδ, using the 5V very low distortion test voltage from my distortion meter, with DC bias voltages of 0V, 18V, 30V, 42V and 60V, using a combination of dry cell and gel batteries.

Distortion was plotted using my standalone distortion tester, with output to the same soundcard and computer software as used for my Electronics World papers, using 4V at 1kHz and with/without 18V bias, for direct comparison with my Electronics World articles.

Satisfied all was well, I decided that distortion testing using 5V 1kHz with 1V at 100Hz test signals and with DC bias voltages ranging from 0V to 60V, might produce better comparisons. To facilitate publication all results were plotted and saved to hard disk, in total some 250 new distortion plots, all completed nearly one year ago, far too many to include in this paper. With the arrival of the spring weather, I was forced to put this work aside for a more urgent task, preparing to plumb in a new low energy central heating system for my home, to replace the old system which had worked so well for many years. Leaving my capacitor distortion findings for completion during our next spell of cold weather.

Apart from the new stacked film capacitors purchased, all other types displayed the by now usual high second harmonic when biased. From these I selected the following 10 median test results for inclusion here:

- The current versions of the 1uF 63V 470 Ecase, wound film capacitor, tested with and without bias voltages, for comparison with those tested for my CapSounds article. See **figures 11 and 12**.

- The current version of the Wima 1uF 63V MKS2 Ecase, wound film capacitor, tested as above, for comparison with those tested for my CapSounds article. See **figures 13 and 14**.

- The stacked film B32560 1uF 63V, shown in **figures 15 and 16**.

- The new MKT obround capacitor, 1uF at 100V. Of the five samples purchased, the first three of this capacitor tested, initially looked to be very low distortion, unfortunately the final two were not, exhibiting much higher distortion, so cannot be recommended. See **figures 17 and 18**.

- My final tests illustrate the benefit of lowering the volts per mil stress on any metallised PET dielectric, simply by opting for a higher voltage rated capacitor. These 1uF 250V rated obround capacitors from Panasonic measured almost identical distortion as the excellent 1uF 63V SMR PPS dielectric capacitors from Rifa I first measured. These Panasonic capacitors are well worth their extra PCB space, as clearly shown in **figures 19 and 20**.

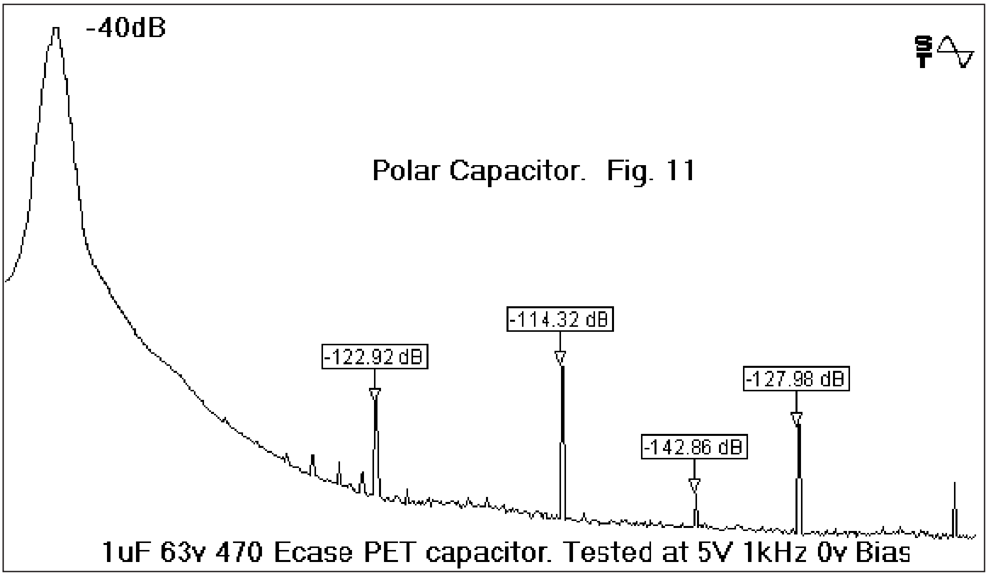

Figure 11. Compared with the 2002 470 style capacitors tested, which were rated as exceptionally good in my Capsounds 4 article, this current production produces rather different distortions. The notable odd harmonics suggest the metallised film may have been resourced.

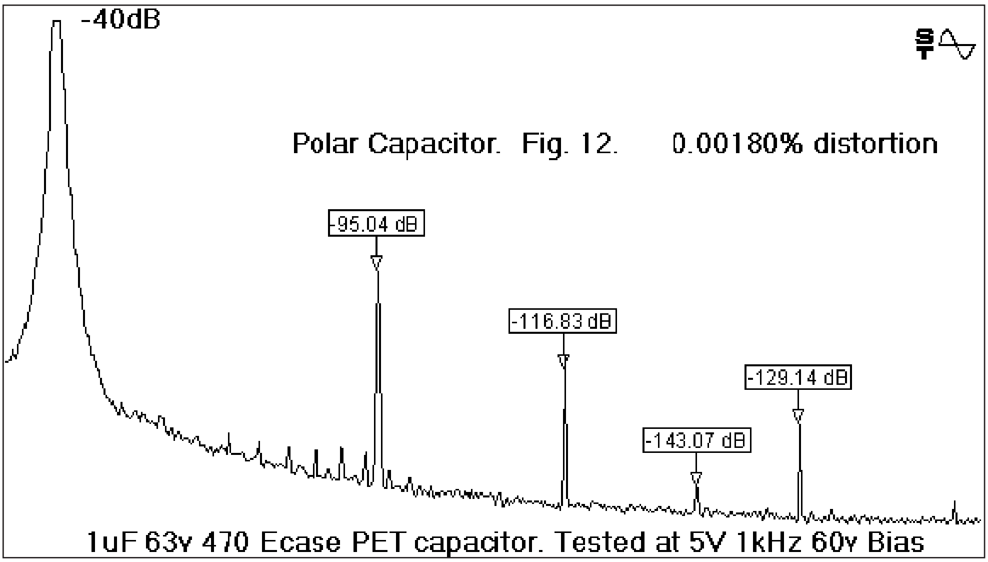

Figure 12. This 470 style capacitor is now clearly not as good as those tested for my CapSounds articles.

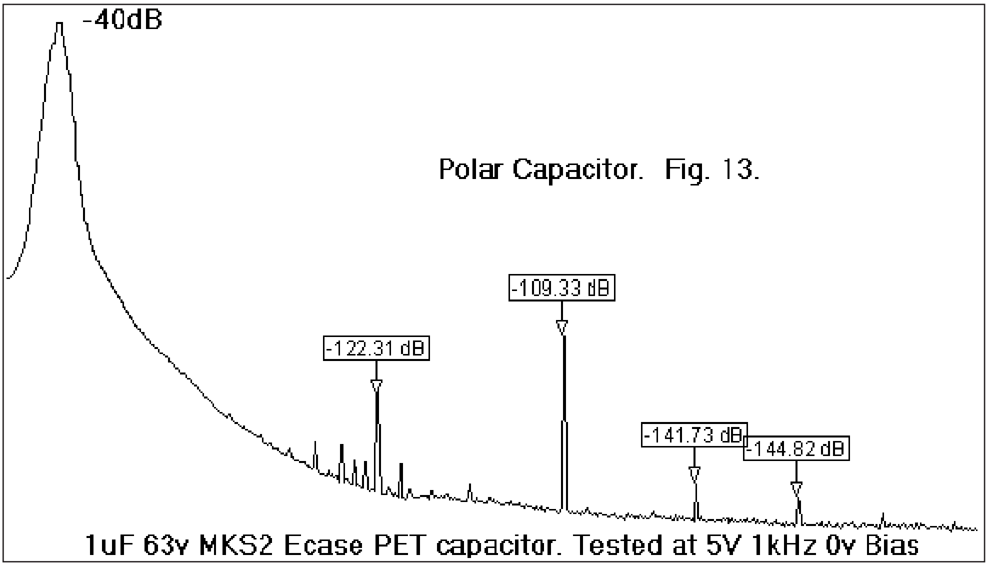

Figure 13. Even allowing for testing using 5V at 1 kHz, compared with my old CapSounds 4V measurements, distortion has notably increased.

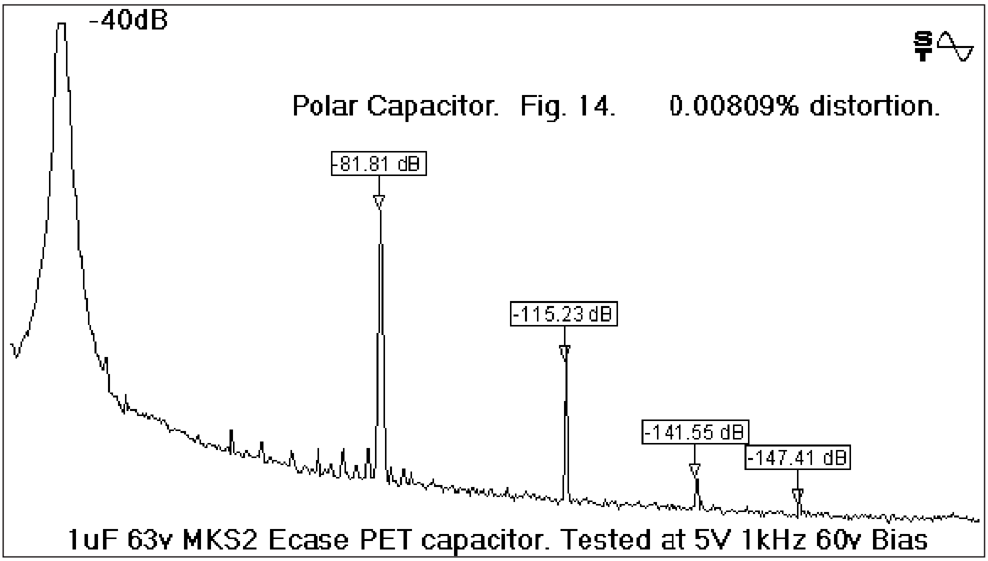

Figure 14. Tested now using this near maximum bias voltage, its distortion has increased significantly to measure even worse than some of the better stacked film capacitors I measured.

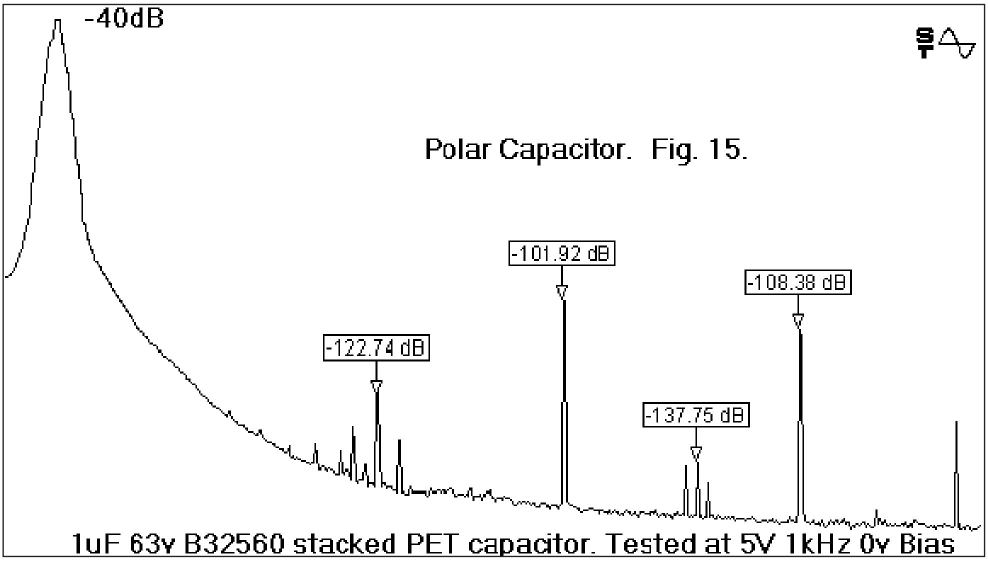

Figure 15. Another stacked film capacitor make, which confirms their typical high levels of odd harmonic distortion as well as their being prone to intermodulation, even with small DC bias voltages.

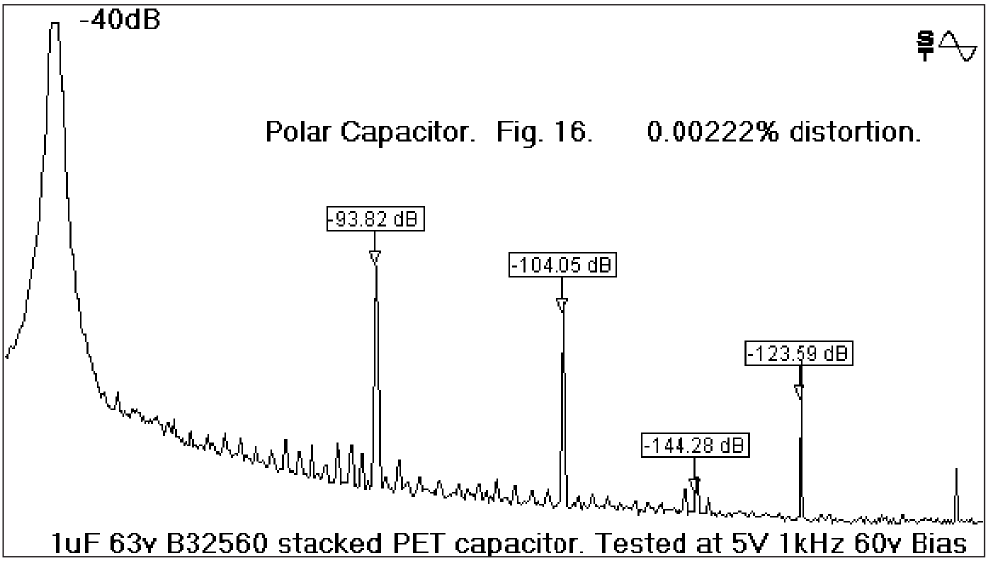

Figure 16. As the above plot, some of these parts measured as good, while others, four of the ten purchased, with more than five times larger distortion than measured for this median distorting sample, were so bad at this high bias voltage as to look unstable. Very high levels of intermodulation.

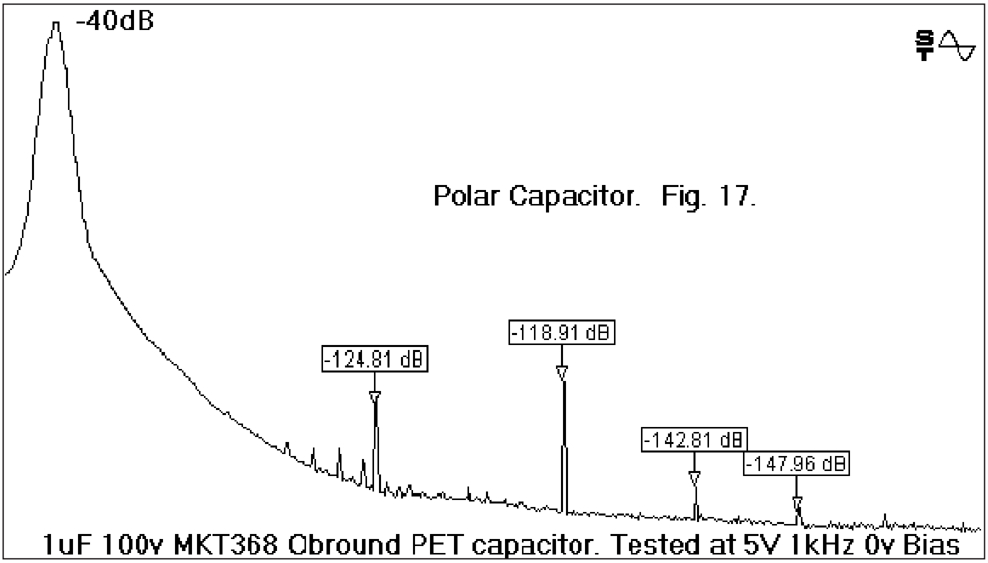

Figure 17. This 100 volt rated capacitor was tested in order to display distortion reduction, simply by a two times increase of dielectric thickness, which increased rated voltage and reduced the applied volts per mil.

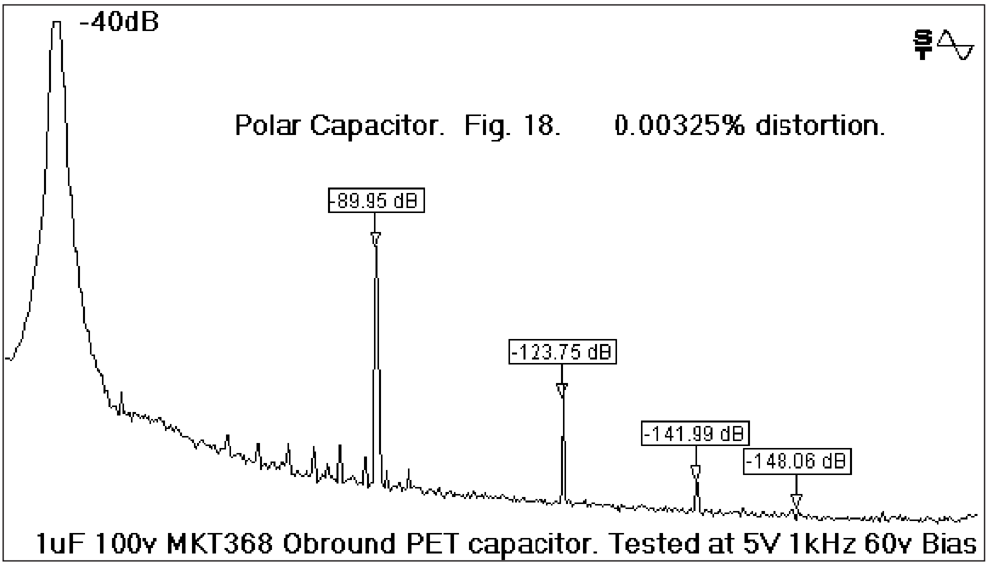

Figure 18. Initially I had great hopes for this capacitor, since three of my five purchased samples, produced notably low distortion. However the remaining two of the five I purchased, as shown above, produced increased distortion, but still less than many of the physically smaller capacitors I tested.

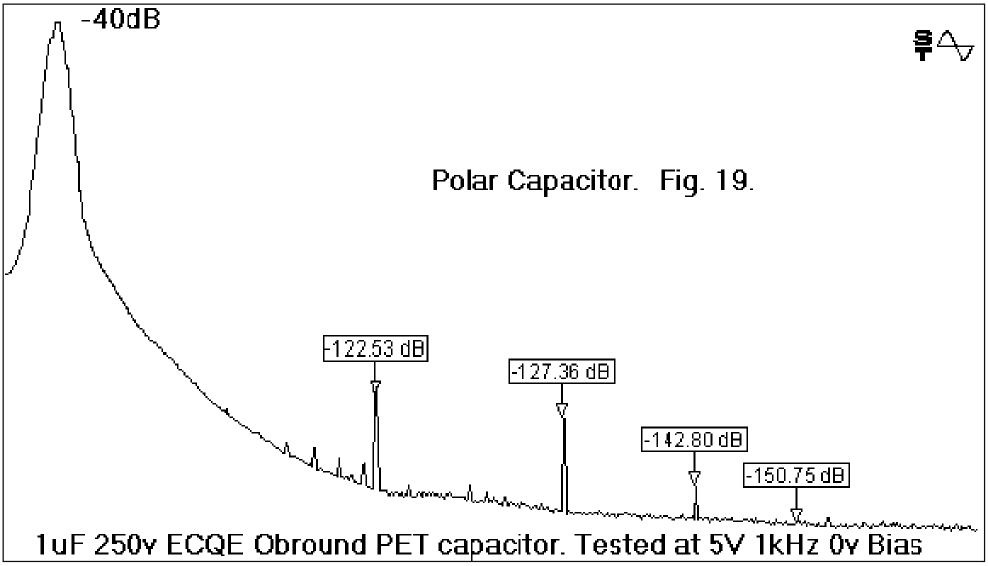

Figure 19. By selecting a five times higher rated voltage, reducing the applied volts per mil, we have a very good, low distortion capacitor. Provided you can allow sufficient board space.

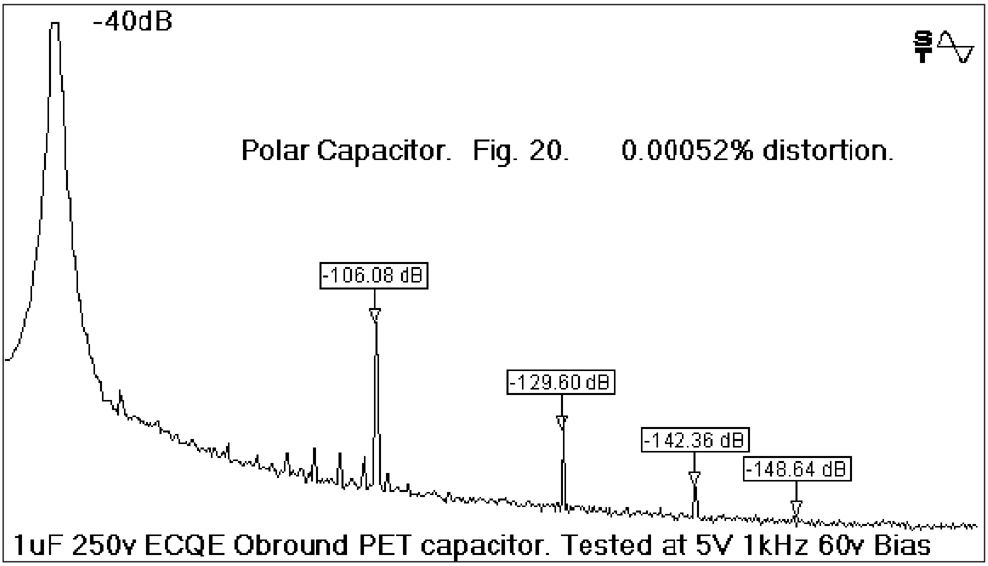

Figure 20. All five samples purchased measured less than 0.001% distortion, even with this 60V bias voltage.

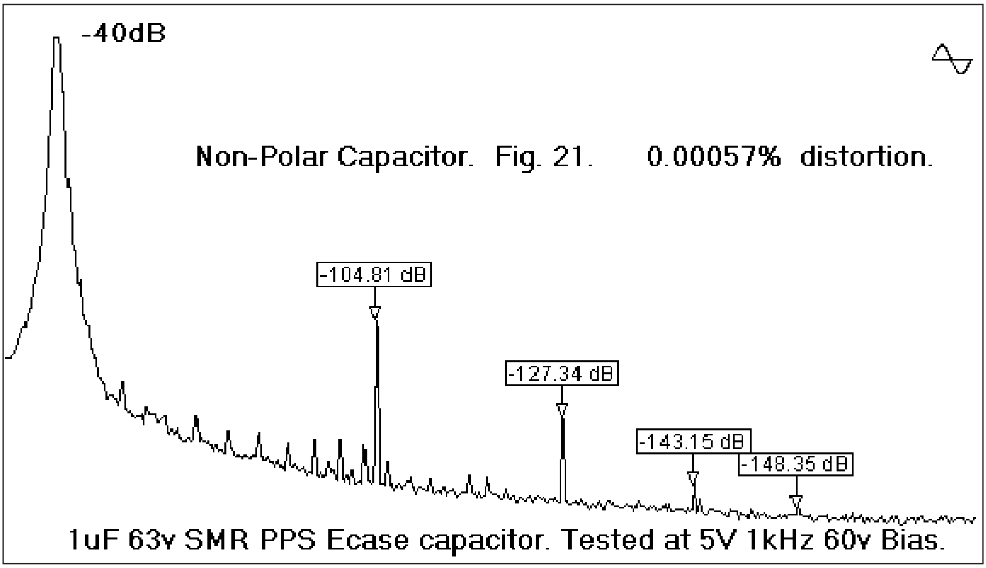

Figure 21. Although a physically very small capacitor, all samples I tested measured less than 0.001% distortion. A truly excellent performance.

Conclusions

From these test results, it should now be apparent that the best way to ensure the lowest practical capacitor distortion, when DC blocking and signal coupling between stages, results from choosing a non-polar capacitor dielectric.

At the present time, sourcing such a capacitor with PPS dielectric, can prove difficult. Far simpler is to choose a physically bigger, higher rated working voltage, polar dielectric capacitor, despite the need for extra PCB space. The above 250V rated polar capacitor is sized at 18.5mm long by 15mm tall, with wire centres at 15mm, whereas the 63V rated SMR PPS non-polar capacitor is 12.5mm long by 12mm tall and wire centres at 10mm. However both plots show near identical performance and the ECQE Panasonic polar capacitor is a distributor stocked item, so is easily available in small quantities.

Reference

[1] Cyril's previous capacitor distortion articles are available at http://www.linearaudio.nl/linearaudio.nl/index.php/my-library/cyril-bateman-s-capacitor-sound-articles, courtesy Cyril Bateman and Electronics World - ed.