Capacitor Sounds II - Distortion v Time v Bias.

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Analysing Capacitor Sound.

My last article described the design and construction of a low cost, real time distortion analysis hardware system, able to measure second and third harmonic distortions from 60dB to 120dB below a 1 volt test signal. Distortion levels are displayed using two alternative methods, a rapid response tree of twenty LED's, showing distortion change in 3dB steps, as well as two low cost DMM meters able to display 0.1dB changes, better accuracy and resolution but slow response while displays settle.

This equipment complements my very low distortion test generator and notch filter / preamplifier assemblies, originally used with a soundcard and FFT software as described in my Capacitor Sounds series of articles. With this I was able to measure distortions imposed onto the test signal by many capacitor types found in high quality audio systems. This test system uniquely provided the facility to measure additional distortions found with most capacitors when subjected to a DC polarising voltage. **REF.1** This DC blocking/polarised usage being a fundamental reason for many, perhaps most capacitor applications.

To reliably measure distortions produced by the better quality capacitors requires a measurement system producing less than 1 ppm distortion, together with a noise floor better than -120dB below a 1 volt test signal. Such equipment, although optimised for measurement of capacitor distortions, is equally suited to measuring and pre-amplifier and power amplifier distortions.

To prove this new hardware method, I measured large numbers of capacitors, comparing the new equipment results with those found using the soundcard/FFT software method. I found excellent agreement between the two methods, but soon noticed that distortions from some capacitors seemed to take a significant time to settle. This was especially noticeable watching the two LED columns, when with some but not all capacitors, the second harmonic display in particular 'ran' up and down the LED column for several seconds after charging or discharging the DC bias voltage. **Fig.1**

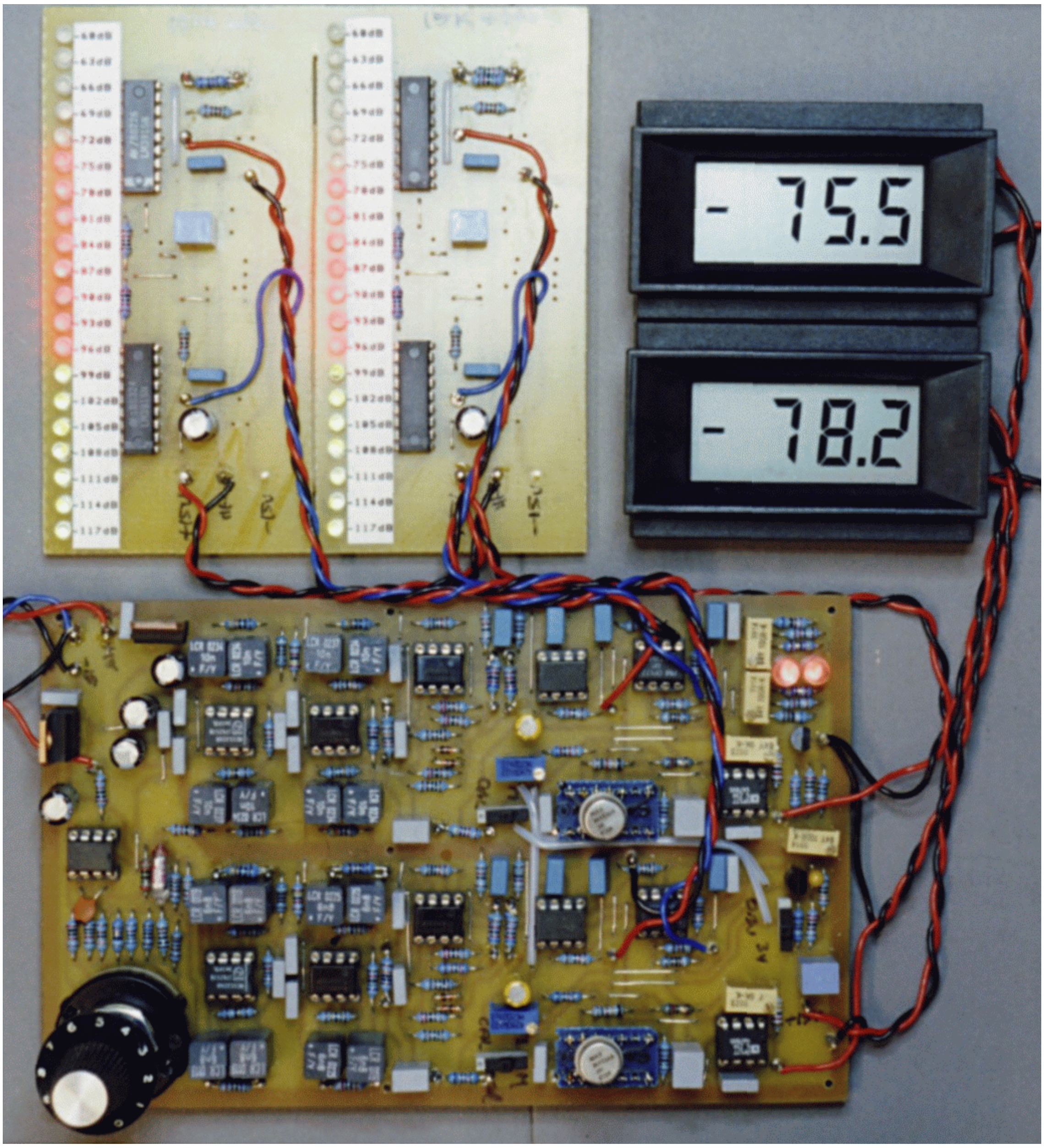

Figure 1) This real time hardware system replaces the soundcard and software used for my earlier series.

Monitoring the second harmonic distortion amplitude at C27 and DC bias across the test capacitor using my Pico ADC100 digitiser, produced the plots for this article.

The upper DMM displays the stabilised second harmonic, the lower the third, testing the 0.1µF X7R ceramic capacitor with DC bias, as figure 1 my last article.

Equipment or capacitor behaviour ?

Careful comparison measurements made using this prototype with those for the computer / soundcard software method confirmed excellent correlation when measuring good, low distortion capacitors. Both methods producing stable distortion measurements with and without DC bias.

Comparing poorer capacitors, especially using DC bias, highlighted capacitor distortion anomalies as the capacitor charges or discharges. These were instantly visible watching the LED trees but masked using the soundcard/software method or the DMM displays, because of the trace averaging time or while the DMM displays settled. However all methods produced almost identical results when the capacitor finally stabilised.

Investigations since made into these anomalies has revealed additional insights into how dielectric absorption really does dominate capacitor sound second harmonic distortion and why the distortion continues to change after the figure 2 capacitor has become fully charged or discharged. **Figs.2, 3.**

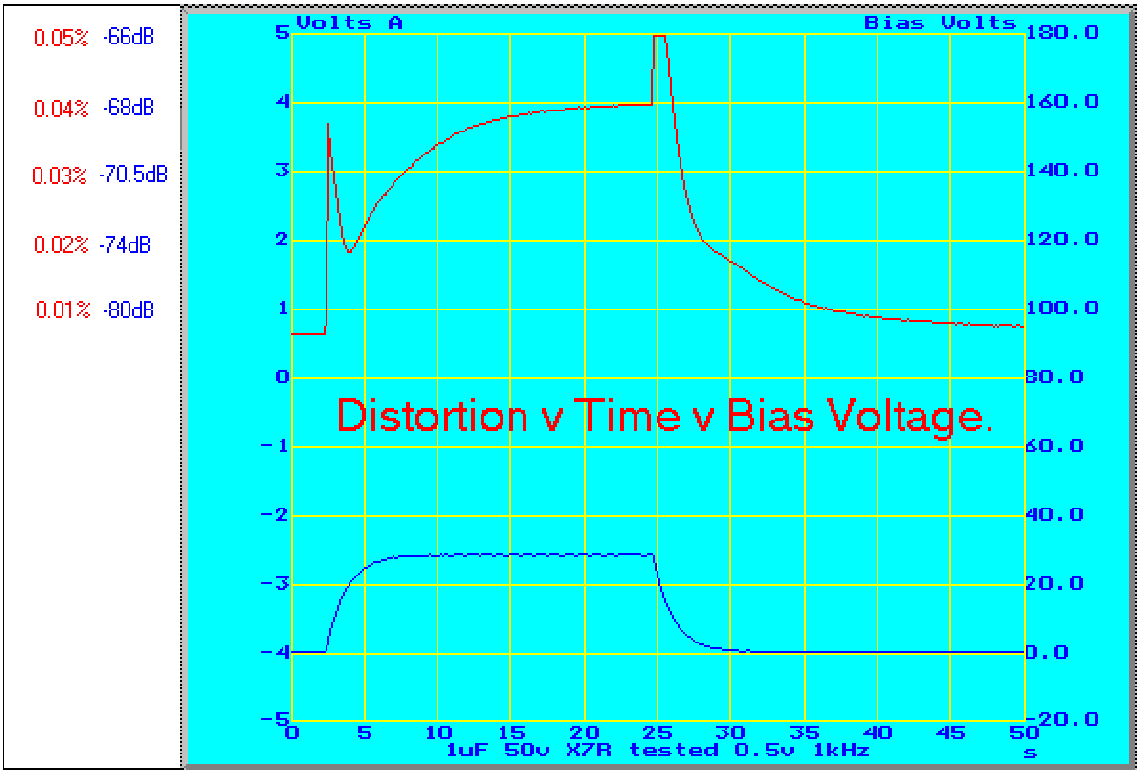

Figure 2) The top plot, left scale, of a 1µF 50v X7R multilayer ceramic using a 0.5v test signal, shows second harmonic increasing then reducing prior to a prolonged settling period, in a capacitor with 1.76% dielectric absorption and a non-linear voltage coefficient. This behaviour was hidden using the soundcard / software method. Bottom trace, right scale, shows DC bias voltage measured across the capacitor.

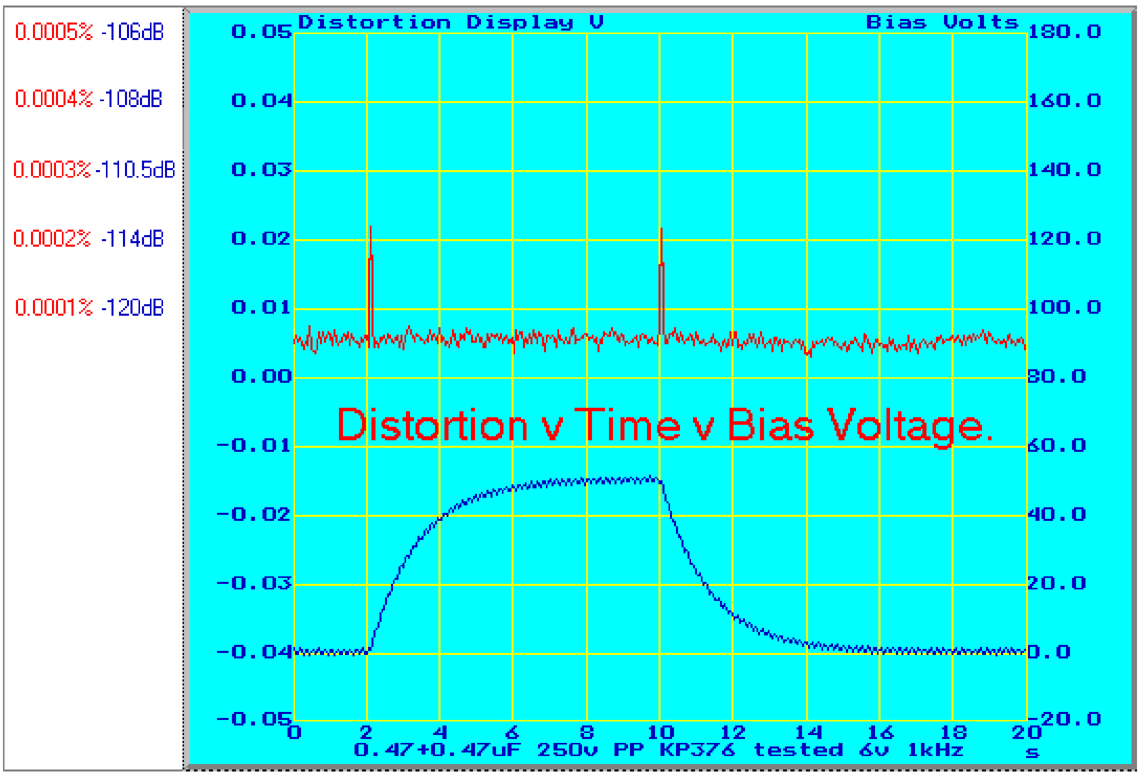

Figure 3) Plot of my 0.47+0.47µF KP376 foil and PP reference capacitor, scaled 100 times more sensitive than figure 2, using a 12 times bigger test signal and 50% more bias voltage.
This 'normal' behaviour shows a near ideal capacitor having no measurable VC and little dielectric absorption . The two switching transients result from operation of the bias charge discharge switch.

Capacitor Anomalies.
In production every capacitor is tested for conformity against four specific departures from the ideal capacitor.

Capacitance value and tanδ at 1 kHz (small values test at 1 MHz, large values 100 Hz) .
Insulation resistance.
Voltage withstand test.

Voltage withstand is always performed using substantially elevated voltages relative to the capacitor's rated voltage. Considered as potentially damaging if repeated, it is defined as a 'once only' test. Multilayer ceramic capacitors will typically be tested using 250% rated voltage for 5 seconds with charging current limited to 50 mA, foil and film capacitors using twice rated voltage for 2 seconds and aluminium electrolytics at their surge voltage rating, usually 120% rated voltage.

Metallised film capacitors are different, typically testing at 160% rated voltage for 2 seconds. One other significant difference results from their use of thin dielectric and 'metallised' electrodes, is that small fault areas in the plastic film dielectric can be 'cleared'. An excess voltage in production evaporates away or 'clears' the metallised electrode surrounding any localised fault areas in the dielectric. If excessive, this clearing could result in non-ohmic electrode areas, increasing third harmonic distortion and dielectric absorption. **REF. 2**

Insulation resistance, usually performed at a much lower voltage, is extremely time consuming so to reduce test times makers usually specify relatively 'easy' limits. These two capacitor voltage tests, apart from any metallised film 'clearing' effects, can have little impact if any on sound distortions generated by a capacitor.

Tanδ. The need to test for capacitance value is obvious, but why measure tanδ in fact what is tanδ ? The theoretically perfect capacitor does not exist, but some construction methods do provide near ideal capacitor behaviour. However all 'solid' dielectric capacitors must exhibit dielectric losses which appear as loss resistances in series and in shunt with the capacitor element, together with small but inevitable series resistances introduced by the metallic electrodes, leadout wires and connections.

In effect each capacitor incorporates a high value shunt and low value series resistor. As a result the phase angle difference measured between the capacitor through current and capacitor voltage for every practical capacitor will always be less than the 90° expected for a perfect capacitor.

Whenever a capacitor is subjected to an AC through current, these dielectric losses and the metallic resistances dissipate some power according to I^2R and the capacitor internal temperature rises above ambient. Except at DC these series resistances dominate capacitor behaviour, so for ease of calculation, all resistive losses are lumped together, resulting in an 'equivalent series' loss resistance or ESR, calculated from the capacitor's measured phase angle.

Because the capacitor has only two terminals we cannot easily identify these individual loss resistances, we can only measure the capacitor's impedance and its voltage/current phase angle, or more usually its two vectors of resistance 'r' and reactance 'x'. The 'r' or resistive vector (ESR) is measured in phase with the capacitor through current, the 'x' or reactance X_c vector 90° later.

Tanδ is simply the result of dividing the magnitude of this 'r' vector by the 'x' vector. Similarly knowing the capacitance value and tanδ at frequency, either from measurement or from makers graphs, we can easily calculate ESR. Simply multiply its reactance X_c by tanδ, taking care to remember that tanδ and capacitance are not constant but do vary with frequency as also must ESR.

Let us explore this ESR.
ESR varies with frequency so cannot have a finite value. This is perhaps the most misunderstood of all capacitor parameters. At low audio frequencies dielectric losses dominate and ESR measures as a value reducing with increasing frequency. At some higher frequency, when the metallic resistances dominate, this ESR reduction slows becoming near constant, then at higher frequencies ESR increases with frequency. When plotted it follows the 'bathtub' shape seen in the attached table of actual measured ESR values, for two typical, good quality capacitors.

Table 1.

Capacitor Type.	100 Hz	300 Hz	1 kHz	3 kHz	10 kHz	30 kHz
100 nF metPET - ESR	38.5Ω	19.2Ω	8.6Ω	4.3Ω	1.8Ω	.75Ω
Measured tanδ	0.0025	0.0037	0.0054	0.0083	0.0115	0.0144
Measured Capacitance	102.4 nF	102.1 nF	101.9 nF	101.3 nF	100.6 nF	99.7 nF
Measured |Z|	15.6K	5.19K	1.56K	523.4Ω	158.2Ω	53.2Ω
100 µF 50v Polar - ESR	507.8mΩ	292.6mΩ	224.5mΩ	203.6mΩ	191.3mΩ	179.4mΩ
Measured tanδ	0.0322	0.0548	0.1384	0.3687	1.095	2.725
Measured Capacitance	100.7 µF	99.4 µF	98.0 µF	96.2 µF	91.2 µF	80.6 µF
Measured |Z|	15.8Ω	5.35Ω	1.64Ω	587 mΩ	258 mΩ	192 mΩ

Clearly even at audio frequencies, capacitor ESR is not constant and does vary with frequency, increasingly so with the best low loss capacitors. Capacitance value also varies with frequency, however in contrast to ESR, capacitance reduction with frequency for the best low loss dielectrics such as COG ceramic, Polystyrene, and Polypropylene is very small. As can be seen in the table, capacitors made using lesser quality dielectrics loose significant capacitance at audible frequencies.

Two Non-tested Anomalies.
Two capacitor anomalies not measured on production capacitors, are voltage coefficient and dielectric absorption.

Voltage coefficient for most capacitors, including COG ceramic, metallised Polyester and Polypropylene film types is so small as to be almost impossible to measure. The exceptions are high 'k' ceramics and electrolytics. Voltage coefficient or VC for high 'k' ceramics is controlled according to their CECC, MIL and EIA classifications, e.g. BX or 2X1 grade capacitors must lie within +15% and -25% of nominal with maximum rated DC volts applied. Each batch of these capacitors will be QA sample tested to ensure compliance.

Dielectric Absorption or DA is another matter, I know of no similar classification which monitors DA for any type of capacitor. Two common methods exist for measuring DA, both are essentially slow DC methods, having no direct correlation to AC usage. The most common being to charge the capacitor to a known voltage for a long time, briefly discharge through a low value resistor for a few seconds then allow to recover for some time before measuring 'recovered' voltage using a very high impedance voltmeter. The alternative method performs the opposite test by measuring capacitor charging current over a long time.

The problem with both tests is deciding on the charging voltage to use. Generally the capacitor rated voltage is used, but most capacitors in transistor equipment are used with much smaller DC polarising voltages, even with little or no DC bias voltage.

Tests performed for this article.
To investigate the anomalies illustrated between figures 2 and 3, I needed to explore the affects change in voltage coefficient, tanδ and DA have on second harmonic distortion. Ideally I needed to find and measure capacitors having no measurable VC or DA, no measurable VC but large DA, large VC and no DA and some exhibiting both anomalies.

Apart from allowing sufficient time for the capacitor to stabilise, measuring capacitance and tanδ with bias voltage is easily performed. The DC bias adapter used with my 100 Hz distortion test equipment also attaches to my 0.1% Wayne Kerr bridge. Assembled using 450 volt AC rated, series wound, metallised Polypropylene capacitors with no measurable VC, this bias adapter has been proved free from distortion to 100 v DC and was used for all measurements, with and without bias voltage.

Voltage coefficient of film capacitors is so small as to be in practise un-measurable, so unusual measures were needed to derive some figures for this investigation. In addition to the obvious need to maintain a constant room temperature I found it essential to shield the smaller capacitors from normal room air movement and low temperature infra-red. An inverted, black plastic, empty 35 mm film canister, was placed over the capacitor which was allowed to stabilise for some 10 minutes following each bias voltage increment.

Dielectric absorption is even more time consuming and considerably more difficult to measure accurately. Most 'standard' test circuits require the use of an exceptionally high input impedance voltmeter with 15 minutes charge and recovery times. **REF. 3** The usual 10 MΩ DVM discharges recovering 1μF capacitors before a reading can be taken, so conventional instruments simply will not do. I considered using a very high input impedance FET opamp buffer, but the best type I had to hand exhibited a 50 pA bias current, sufficient to charge or discharge many capacitors.

I also had a matched pair of low cost PM128 panel meters, these claim a high input impedance as supplied set to measure 200 mV full scale. Their voltage readings were almost unchanged when a 100 MΩ resistor was added in series, confirming they did have an exceptionally high input impedance. I decided to use these to measure two capacitors at one time. With the expected 0.5% DA typical for PET, a capacitor charged to 30 volts would require some 150 mV recovery voltage to be measured, well within the PM128 meter's 200 mV range. Any larger DA would be measured using a 100 M Ω divider.

A very high voltage, 40 mm diameter porcelain two gang four way rotary wafer switch facilitated switching from charge to discharge, to recovery then to measure, the two co-tested capacitors. In this way the PM128 meters would only load the capacitors for a few seconds while noting the readings. Following a few trials this method worked well with good repeatability, provided I used a stop watch to time the discharge period. For this I choose to use ten seconds, discharging the capacitors into a 56 Ohm resistor.

After many measurements I managed to locate a number of suitable test capacitors matching three of my four target VC and DA grades. The problem being all attempts to identify a capacitor with high VC and no DA failed. On reflection it is almost certain that particular combination does not exist in production capacitors. I managed to find several good examples showing little or no VC and DA, but only one showing almost no VC and large DA and many samples showing various levels of both anomalies.

In the end to restrict the number of figures for this article, I selected three 1 µF capacitors of roughly similar size and 200-250 volt DC rating, also three same case size 1 µF 63v rated metallised PET and one metallised Polyphenylene Sulphide type.

Test Capacitors.
Measuring the voltage coefficient of the X7R dielectric ceramic capacitor of figure 2 revealed a large and non-linear effect. Initially capacitance increased with DC bias, but from 12v to 39v it reduced more than 5%. This high 'k' X7R ceramic type also shows measurable change of tanδ with DC bias voltage, 0.0119 at 0v, 0.0149 at 12v and 0.0139 with 30v DC bias. **Fig. 4.**

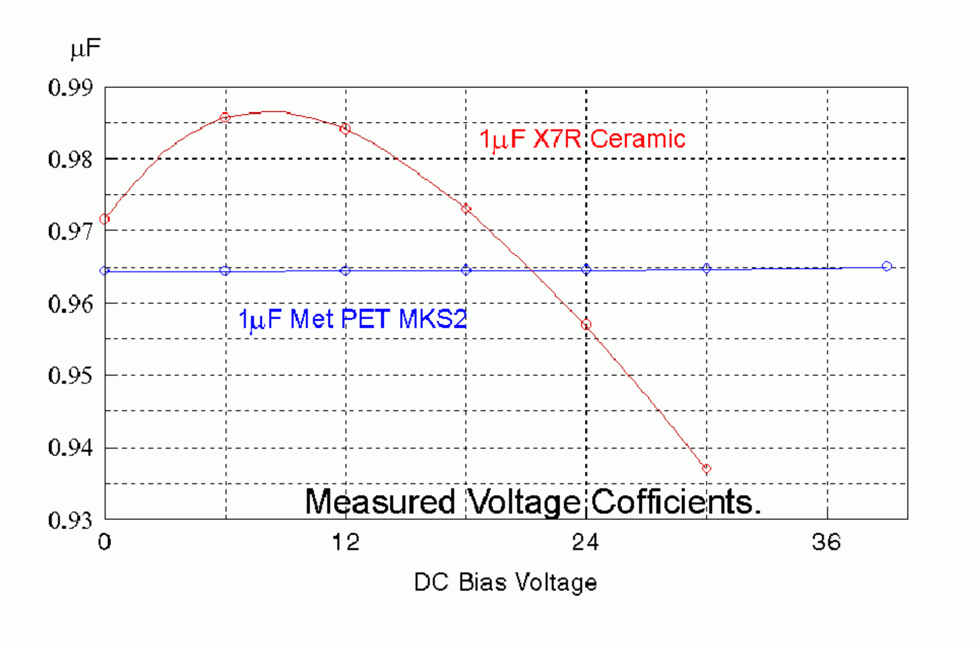

Figure 4) The large and non-linear voltage coefficient of the figure 2 high 'K' X7R multilayer ceramic compared with the tiny VC of the MKS2 metallised PET capacitor. This MKS2 VC, the largest of the film capacitors I measured, was absolutely linear from 6v to 24v bias increasing by just 0.031%.

Even larger changes were found measuring Z5U type capacitors.

COG ceramic types, whether multilayer or single layer discs, are quite different in every respect. They have no measurable voltage or tanδ coefficients and their ±30 ppm temperature coefficient cannot be bettered, they are much more stable than Mica or plastic film capacitors. Measuring the 100 nF 50v COG types featured in my earlier articles, even the fifth significant figure of capacitance and tanδ remained unchanged, when bias was increased in 6v steps from 0 to 30 v DC.

Other capacitors I measured fell within these two extremes. With 48v bias my 0.47+0.47µF 250v KP376 FKP aluminium foil and Polypropylene, near perfect reference capacitor, increased in value by only +0.0053%. The 1 µF 250v Epcos B32653 metallised Polypropylene measured +0.005% while a 1 µF 200v B5030KZ impregnated metallised paper measured slightly more, a barely measurable +0.03% voltage coefficient. Tanδ for all three capacitors remained unchanged with/without DC bias.

Dielectric absorption for these three capacitors however differed substantially. Both Polypropylene types measured extremely small DA but the impregnated paper capacitor exhibited an enormous 12.74%. The FKP capacitor measured 0.04% and the B32653 MPP 0.052%. More significantly while the recovery voltage for both PP types builds steadily and slowly with time, that for the paper capacitor increased almost instantly to a very high value, reaching 3.38% in just 1 minute, almost one hundred times larger than the PP capacitors fifteen minute value. **Fig. 5**

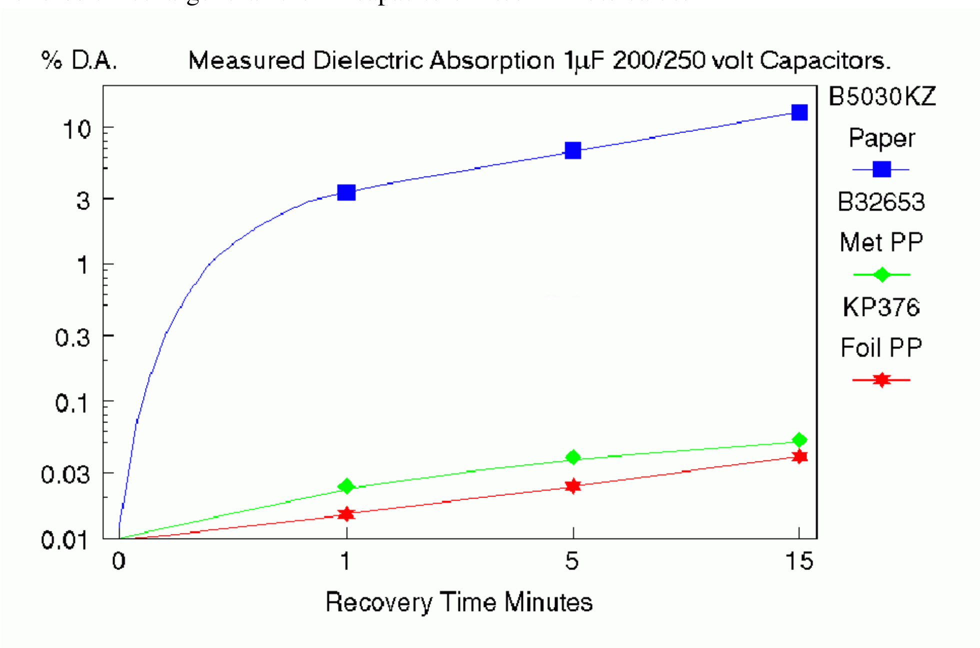

Figure 5) Dielectric absorption recovery voltages, comparing the 12.74% DA of the 1µF 200v rated impregnated paper type B5030KZ of figure 6 with the 0.04% of my near ideal 0.47+0.47µF 250v type KP376 foil and Polypropylene reference capacitor of figure 3 and a good MPP capacitor.

These DA differences clearly show in the distortion with time as well as the conventional FFT soundcard plots. With no DC bias both the paper and FKP capacitors measured almost identical second harmonics at -127.3 and -127.5 dB respectively, the B32653 MPP -126.8dB. With 48 v DC bias, second harmonic of the FKP increased just 1 dB, the B32653 MPP type increased by 6.3dB, but second harmonic for the metallised paper capacitor increased by 13 dB. More significantly, the FKP distortion time plot appears unchanged with/without bias or time. In contrast the plot for the paper capacitor clearly shows second harmonic distortion continuing to build slowly, increasing and decreasing over many seconds. **Figs. 3, 6**.

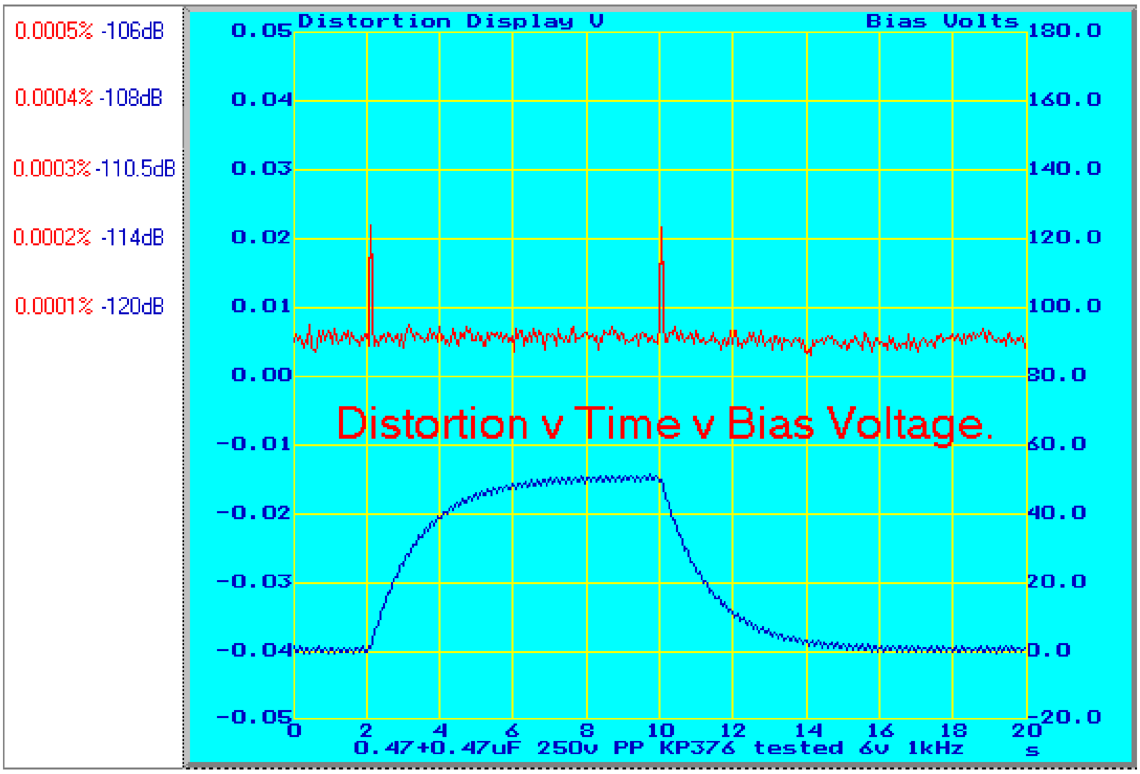

Figure 3) repeated Plot of my 0.47+0.47µF KP376 foil and PP reference capacitor.

This 'normal' behaviour shows a near ideal capacitor having no measurable VC and little dielectric absorption .

The two switching transients result from operation of the bias charge discharge switch.

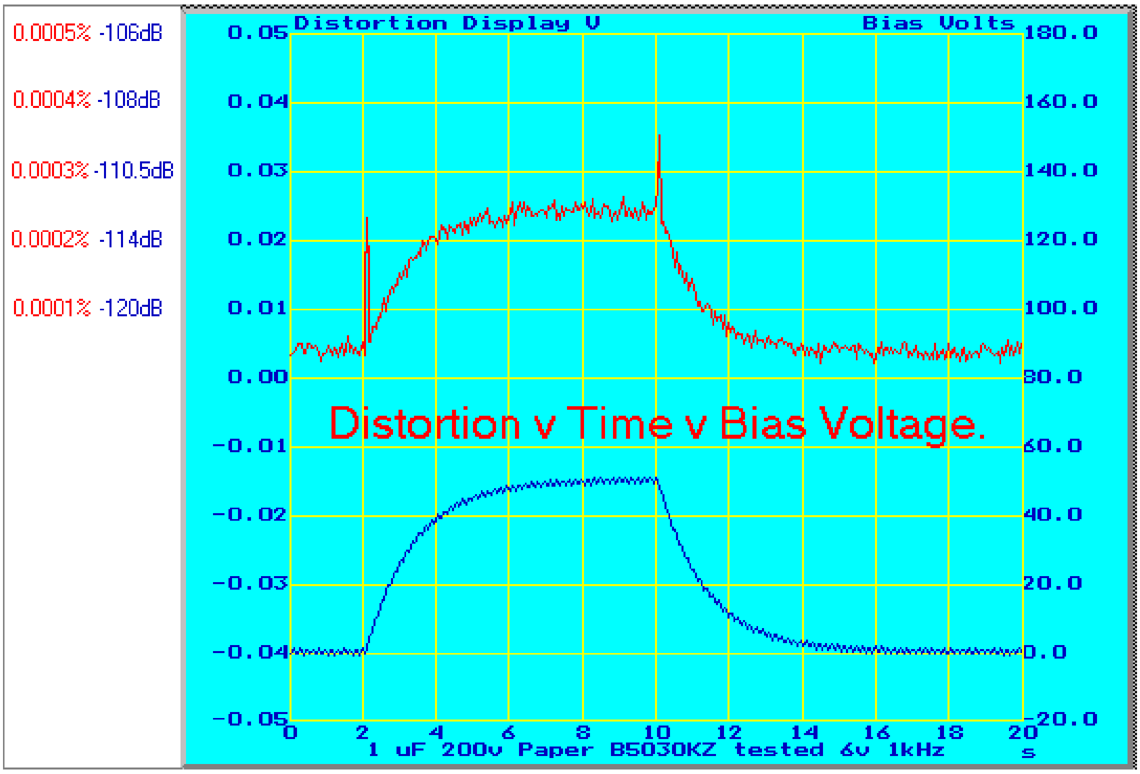

Figure 6) 1µF 200v impregnated paper B5030KZ type capacitor with a negligibly small 0.03% voltage coefficient but very large 12.74% dielectric absorption, shows how dielectric absorption and DC bias voltage dominate second harmonic generated by the capacitor.
With no bias both this and the fig. 3 capacitor measured almost identical second harmonics, -127.3 and -127.5dB respectively.

Rather surprisingly I also measured significant differences of VC and DA between the three same case size, 1 µF 63v rated, metallised PET capacitors. While the two BC Components capacitors, 370 and 470 types show closely similar DA recovery voltages, the Wima MKS2 type shows much increased DA, at 0.724% almost double that of the other two metallised PET capacitors.

As expected the Evox metallised Polyphenylene Sulphide capacitor, which performed so well in my earlier tests, measured 0% VC and only 0.087% DA when co-measured with the 470 style capacitor, to make a direct comparison with that style's 0.4% DA. **Fig 7.**

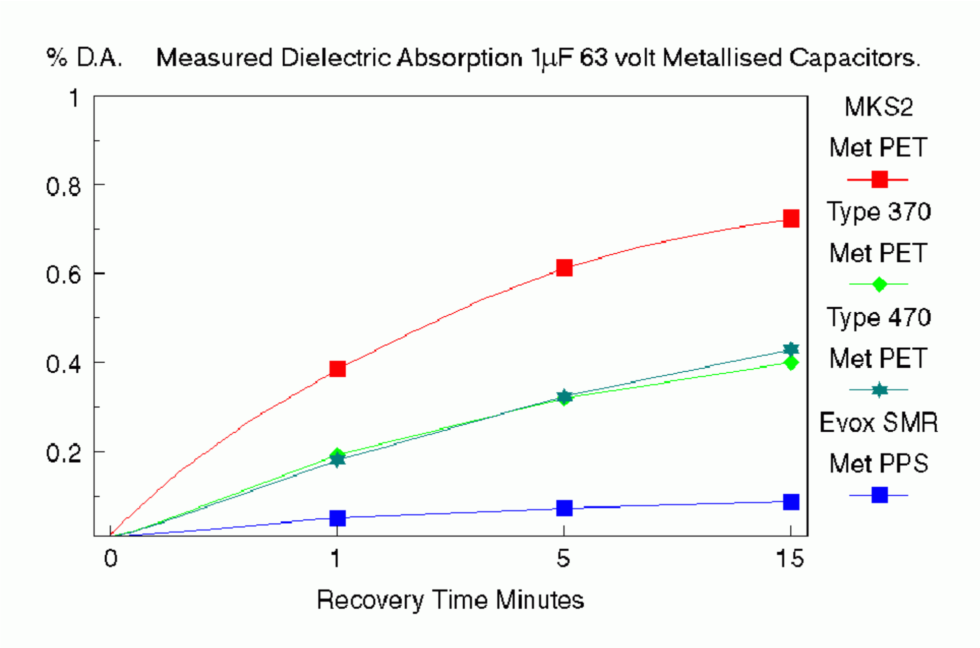

Figure 7) Recovery voltage comparing three different 1µF 63v rated, same case size, metallised PET capacitors with a slightly larger case metallised Polyphenylene Sulphide capacitor. While the two BC Components types, 370 and 470 show similar DA the Wima MKS2 measured almost double and produced the worst distortion of these four capacitors.

Three of these four quite similar capacitors also measured very small and linear VC when tested using 0 to 30v DC bias, ranging from 0% for the Evox to a negligible 0.0049% for the 470 and 0.024% for the 370 style. The MKS2 style measured the worst with 0.031% at 30v and 0.062% by 39v. Its VC was ruler straight from 6v to 24v bias, with a small dip from 0v to 6v and increasing deviation above 30v bias. see **Fig 4.**

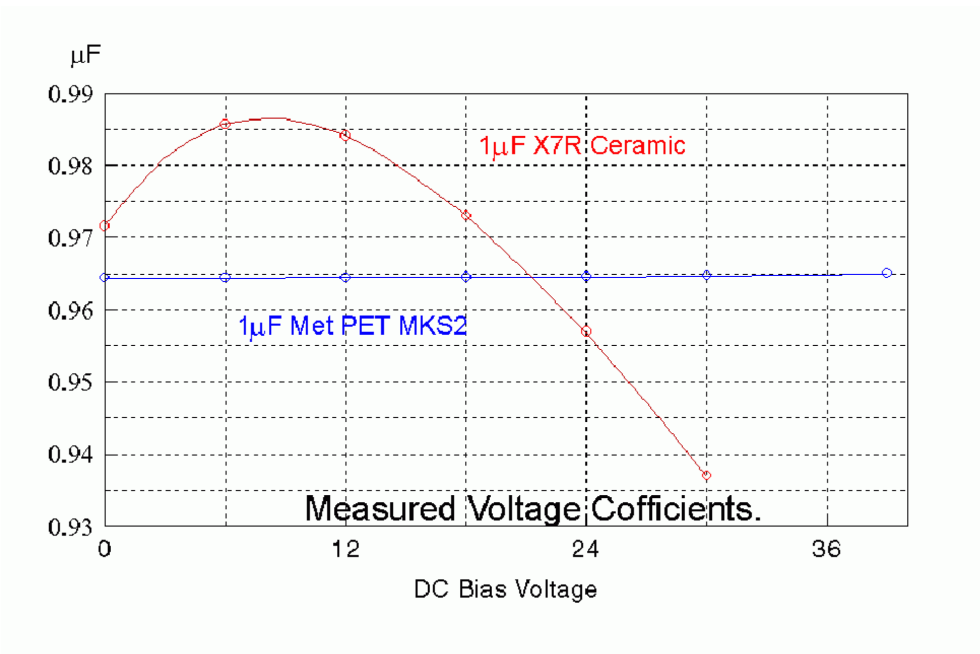

Figure 4) repeat. The large and non-linear voltage coefficient of the figure 2 high 'K' X7R multilayer ceramic compared with the tiny VC of the MKS2 metallised PET capacitor.

This MKS2 VC, which has the largest VC and DA of the film capacitors measured, was absolutely linear from 6v to 24v bias increasing by just 0.031%.

Notably of the 63v capacitors tested, DA of this MKS2 type measured almost double that of the other Metallised PET types.

The distortion with time plot for this MKS2 capacitor shows a noticeable dip then increase in second harmonic as the capacitor discharges and another small dip, not seen in other capacitor plots, as it charges. With such a range of measured distortions, I had no choice but change scales. The Evox SMR also BC Components type 470 were measured using the 0.05 volts for -106dB full scale display, but for the type 370 and the MKS2 capacitors I had to use the 0.5 volt, -86dB full scale display.

Most notable of all is that even with no DC bias the MKS2 measured some 10 dB more second harmonic distortion than the other two metallised PET types. Due to its large DA of 0.724% it also displayed the largest increase of second harmonic, more than +26 dB with 39v bias despite starting from a higher unbiased level, -115dB, than the others. This behaviour was not unique to this particular specimen but found in others of the same style. **Figs. 8, 9, 10, 11.**

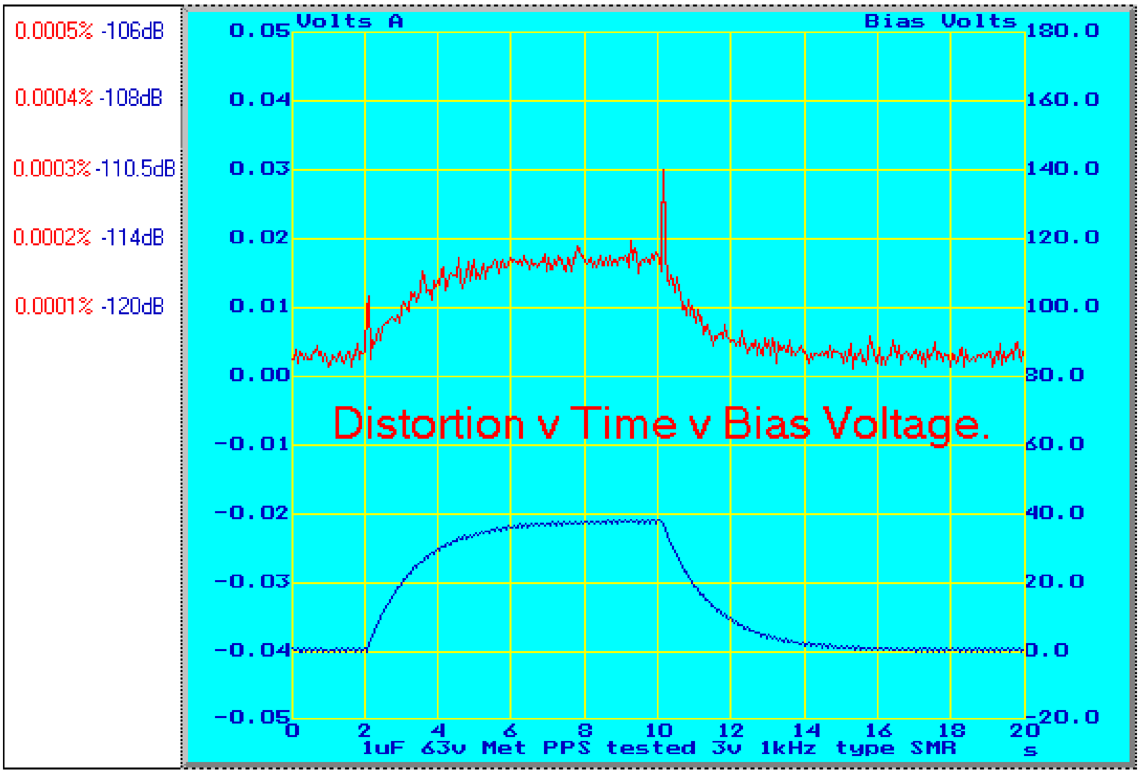

Figure 8) This Evox SMR 1µF 63v capacitor size 12.5∗6mm, with 0% VC and 0.087% DA, shows a 10dB increase in second harmonic with DC bias, half that measured with the best metallised PET capacitor tested, figure 9 and compares well with the 6dB increase of the 26∗10mm B32653 MPP type.

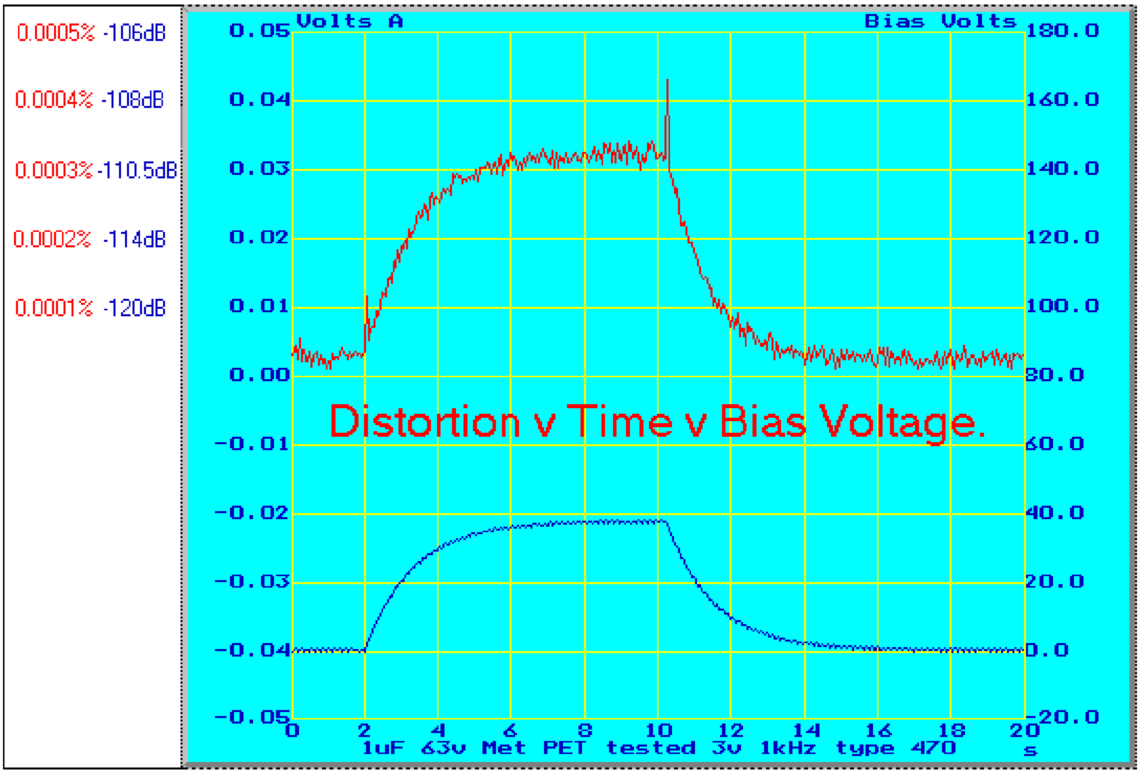

Figure 9) BC Components type 470, 1µF 63v metallised PET capacitors consistently measure a small second harmonic without DC bias and negligible 0.0049% VC.

However with its 0.4% DA, second harmonic increases by 19.9dB with bias.

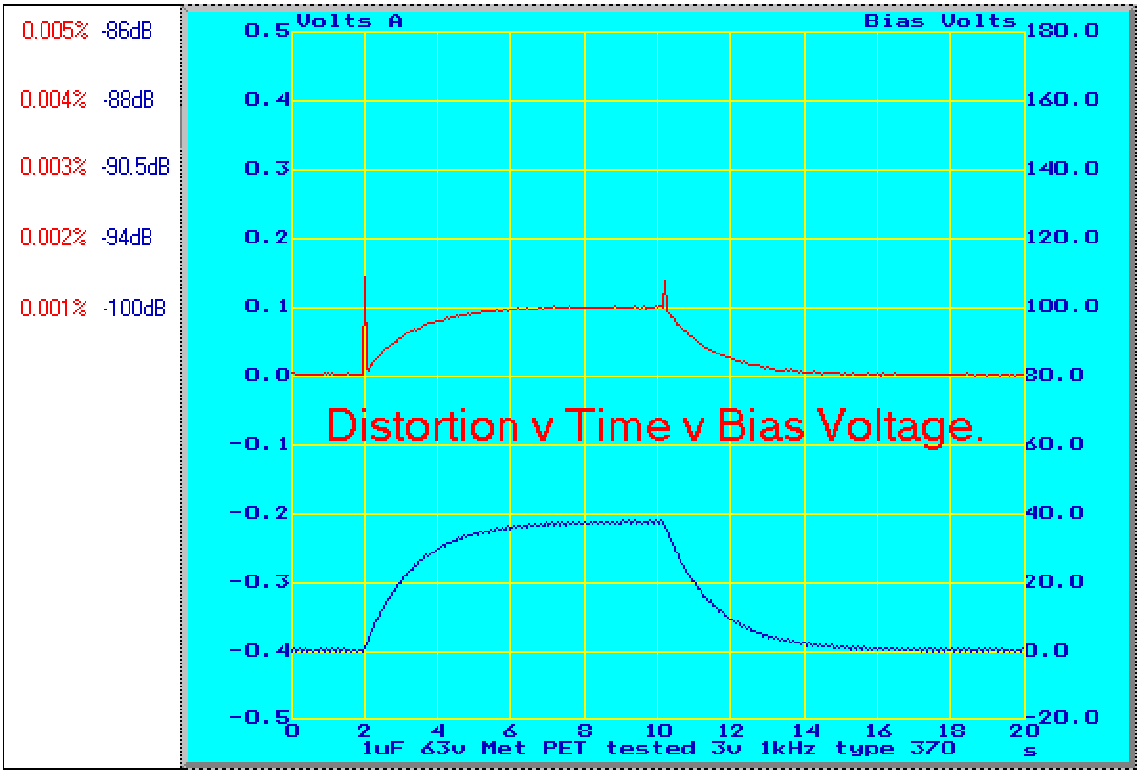

Figure 10) The same makers 370 type shows 4dB more second harmonic with no bias and 25.3dB increase with bias, tested under the same conditions, enforcing use of a less sensitive display scale.

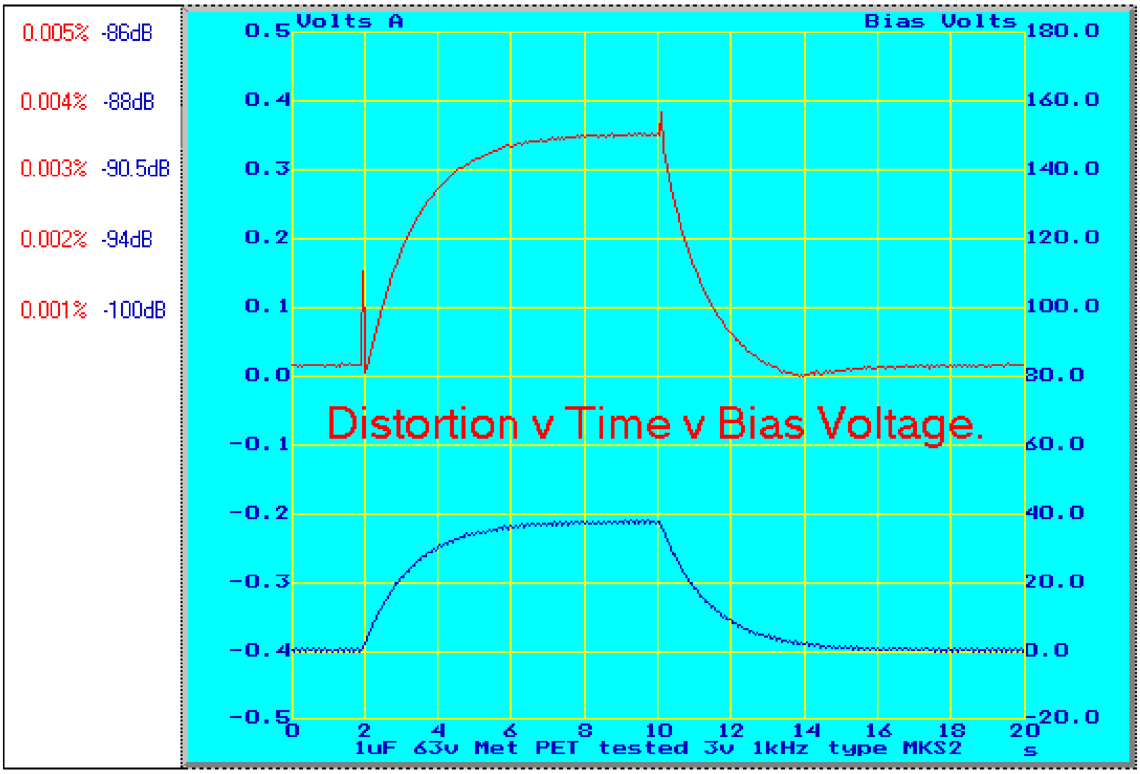

Figure 11) With and without DC bias voltage the same case size Wima MKS2 shows much more distortion than the other capacitors. While discharging, its no bias second harmonic overshoots then slowly rebuilds to -115dB, 10dB worse than the others.
With bias, second harmonic distortion, -88.5dB is ten times larger than type 470 and twenty times that of the Evox SMR capacitor.

Conclusions - VC or DA ?
As preparation for this article I carefully measured more than one hundred capacitors. As can be seen in figure 2 a large dielectric absorption combined with a large non-linear voltage coefficient does seriously affect the level of second harmonic distortion produced by a capacitor. However such large and non-linear voltage coefficients simply do not exist in COG ceramics, foil and film or metallised film capacitors. Some metallised PET capacitors do exhibit a small almost un-measurable voltage coefficient, much too small to account for the increased second harmonic distortions I measured with the capacitor DC biased.

Using a Spice type simulator, Microcap6 and the advanced harmonic balance simulator in Aplac7.62, I explored the effect a change of DC bias has on capacitor distortions. Applying change of DC bias to a capacitor stressed with a constant AC test signal simply moves the test signal zero crossing, along the voltage coefficient plot. With no DA and a non-linear VC plot, distortion changes in-line with the degree of VC non-linearity. Given a linear VC and no DA distortion remains unchanged with bias, but when a linear VC was combined with a DA model and bias applied, my simulated distortions increased.

Significant non-linear voltage coefficients will inevitably be found in high ‘k’ ceramic capacitors and to a lesser amount, typically 0.2%, in aluminium and tantalum electrolytics, but from my tests are not found in other capacitor styles.

VC

Voltage coefficient is in practise so small as to be in practice un-measurable for COG ceramic and the better film dielectrics such as Polystyrene, Polypropylene and Polyphenylene Sulphide. Metallised PET capacitors do exhibit a small near linear VC, but not usually of sufficient level to visibly affect distortion measurements.

DA

The better dielectrics such as COG ceramic, Polystyrene, Polypropylene and Polyphenylene Sulphide do exhibit a small but measurable dielectric absorption, usually less than 0.1% which has little effect on second harmonic distortion even when DC biased. However as has also been clearly demonstrated, less than 0.5% DA, found in many perhaps most, metallised PET capacitors, does result in substantial increases in second harmonic distortion with increasing DC bias. From these tests, dielectric absorption is shown to be the dominant second harmonic distortion mechanism for COG ceramic and plastic film capacitors, especially when DC biased.

These test results reinforce my earlier recommendation that metallised PET capacitors should either be individually distortion tested before use, or simply not used in any quality audio system. **REF.4**

In my next article I explain how my real time second and third harmonic analyser described in the July issue, together with my 1 ppm low distortion 1 kHz generator, buffer amplifier and notch filter preamplifier **REF.1** can be assembled into a low cost case, as a self contained free-standing distortion analyser which can be used testing both amplifiers or capacitors.

End.

References.

1) Capacitor Sounds. C.Bateman. Electronics World, July, September, October 02.

2) Understand Capacitor - Film. C.Bateman. Electronics World, May 98.

3) Technical Spotlight, Wima Capacitors. http://www.wima.de/spotlight/spotlight.htm

4) Capacitor Sounds. C.Bateman. Electronics World p.40, November 02.

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

Vacuum and air, are little affected by voltage stress. Solid dielectrics which behave in a similar fashion are termed ‘non-polar’. Most solid dielectrics and insulators are affected to some extent, increasing roughly in line with their dielectric constant or ‘k’ value.

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

Non-polar dielectrics such as COG ceramic, Polystyrene and Polypropylene, exhibit small losses but polar dielectrics such as PET are much more lossy. Once charged to a voltage, it takes longer for the electron spin orbits in a polar dielectric to return to their original uncharged state.

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

Various writers have used this method to develop capacitor models which simulate the effect DA has on capacitance value with increasing frequency. For that purpose such models can work well.

In the past I had tried without success however to use these published models with conventional ‘Spice’ simulators, attempting to model the effects of DA on harmonic distortion of capacitors, but none of the published capacitor models proved successful. A particular difficulty being the long simulation times needed to ensure stability and the care needed when choosing the final ‘FFT’ calculation window.

Armed now with the careful capacitor measurements needed for this investigation I was able to refine my models. Using a harmonic balance simulator, developed to calculate distortion in RF circuits, produced usable simulation results, supporting the effects which DA with bias voltage has on distortion.

So how does dielectric absorption affect the distortion produced by a capacitor? The main difference I found is the increasing magnitude of the second harmonic, with increasing bias voltage.