Investigations into the effect of imbalanced mains supply on the idle current operation of toroidal transformers and the effect the Mains Cables R Us filter.

Test setup

While the test described below can be reproduces by any interested party with the required equipment. It does involve dangerous voltages, so should only be attempted with due care for safety procedures, and the author can not be held responsible for any injury that occurs as a result.

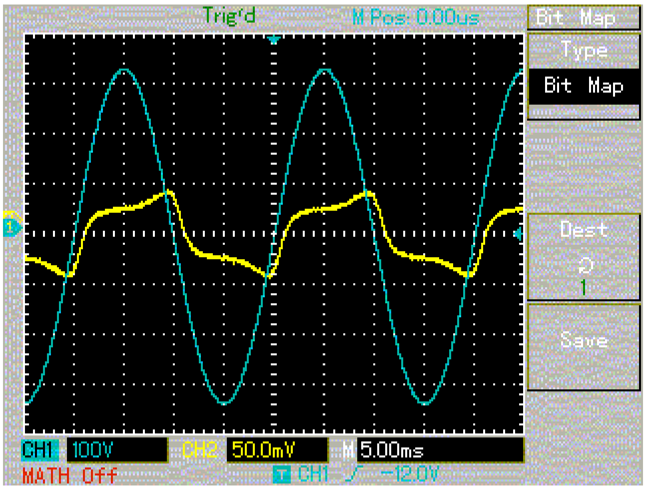
The simulated mains supply for these tests were generated by a lab 240v sinusoidal generator set to produce 230v @ 50Hz. This was then passed through a medical isolation transformer to provide a low distortion and noise floating mains supply. Initial trials were carried out using AC from the wall, but the relatively high levels of distortion found in the resultant sine wave, and the high noise levels obscured the effect of imbalance. Because of this, the lab mains supply was used to provide a notionally perfect mains supply which could then be “corrupted” under controlled conditions and the effects clearly seen.

This supply was connected to the primary of 600va toroidal transformer, similar in construction to that found in high quality audio equipment. The secondary windings of this transformer were left open circuit as we were interested in measuring the effect of the imbalance on the saturation of the transformer core, and the resultant effect on the hysteresis and eddy current losses in the core of the transformer.

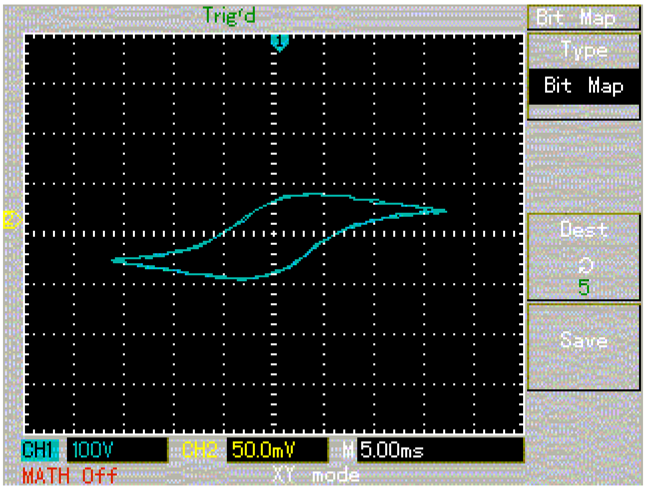
The current through the transformer was measured by a digital storage oscilloscope across a 4R7 sense resistor in series with the primary of the sample transformer; the voltage across the primary was also measured by the same DSO

For the tests, the mains supply was asymmetrically loaded by the addition of a 10k resistor and silicon diode in series, places across the output of the isolating transformer. The loading circuit was before the sense resistor, so the DSO measured the effect of the imbalance on the sample transformer, and not the additional current drawn by the loading circuit.

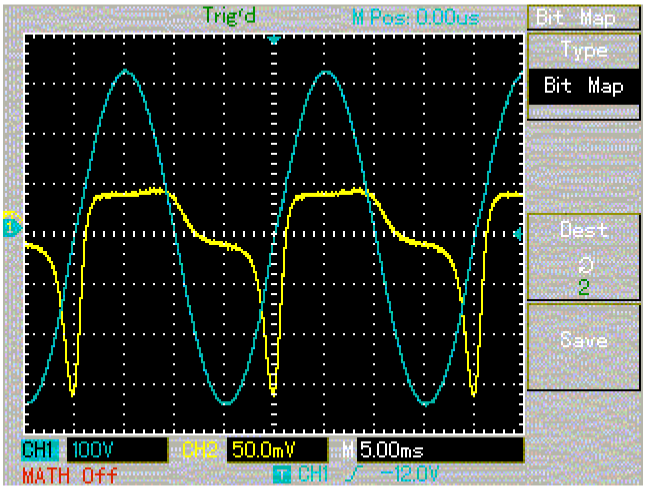
Test Results



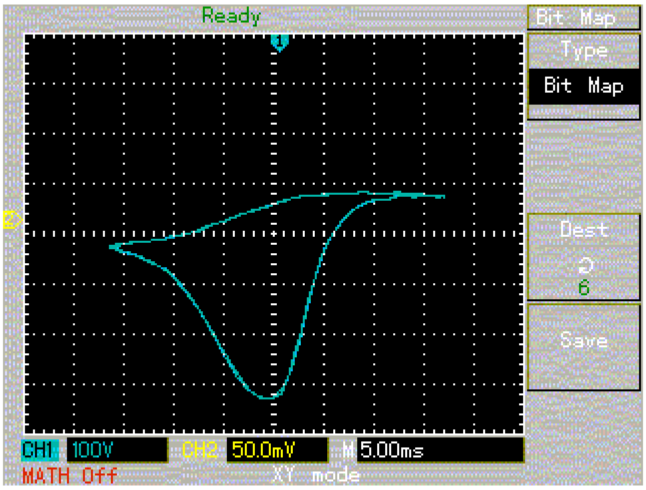
Here we see the voltage (blue trace) and current (yellow trace) drawn by the sample transformer. This is without the asymmetric load applied and the filter is not in the circuit. The current trace is nicely symmetric. It may be expected that the current trace should also be a pure sine wave, but the current is a result of the losses in the transformer core and as such follow the standard hysteresis curve for ferromagnetic materials. This curve can be clearly seen, by changing the display to show the voltage against current display.



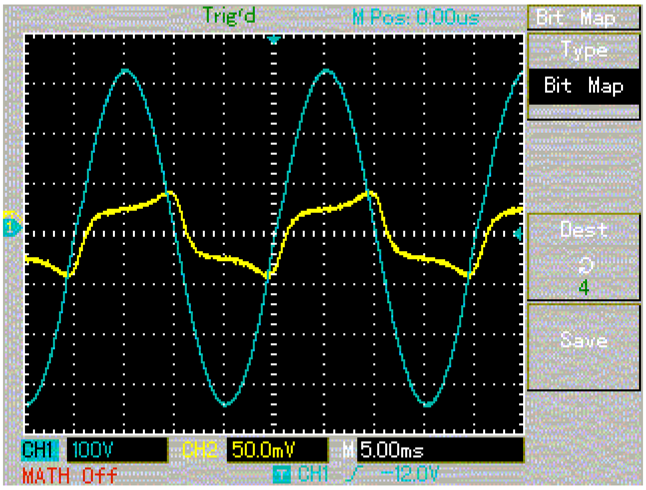
This now shows the classic hysteresis curve for the core of the transformer, rotated slightly by the inductive nature of the isolation transformer supplying the test setup.



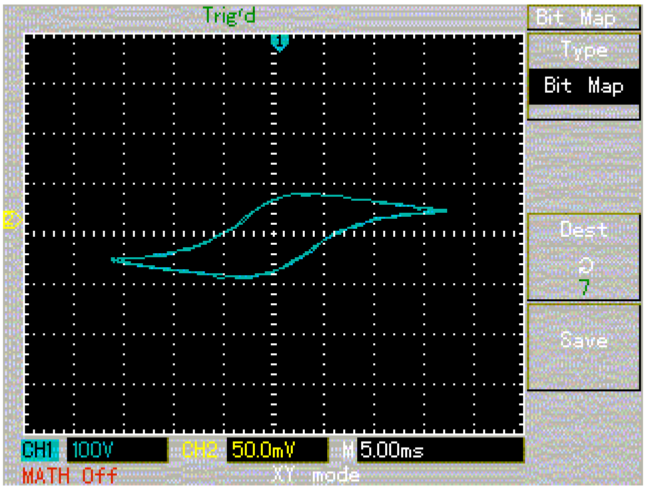
The display now shows the effect of applying the asymmetric load. The current in the transformer is now far from symmetric. It should also be noted than the small imbalance in current is not visible in the voltage (blue) trace, showing that very small offsets to the supply waveform have large effects on the operation of the transformer. If we were only monitoring the source voltage these effects would not be apparent.



The corresponding XY display of the system shows how the losses in the transformer have increased (the area inside the curve is directly proportional to the energy loss in the transformer)



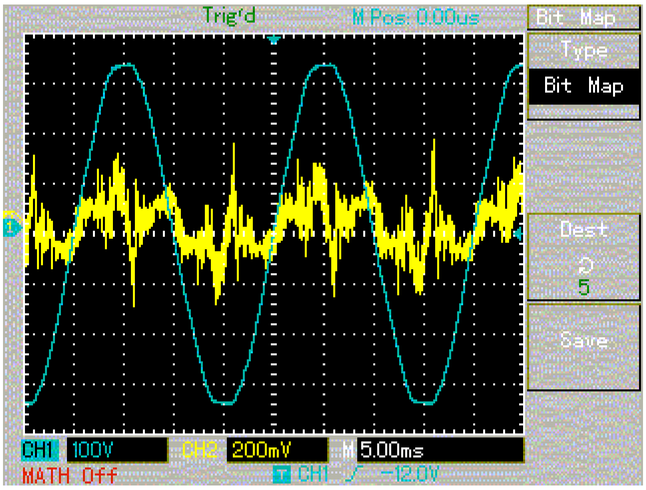
We have now introduced the filter unit inline with the sample transformer and the symmetric current trace is restored to its previous shape, showing that the filter has isolated the sample transformer from the effect of the asymmetric load on the mains supply.



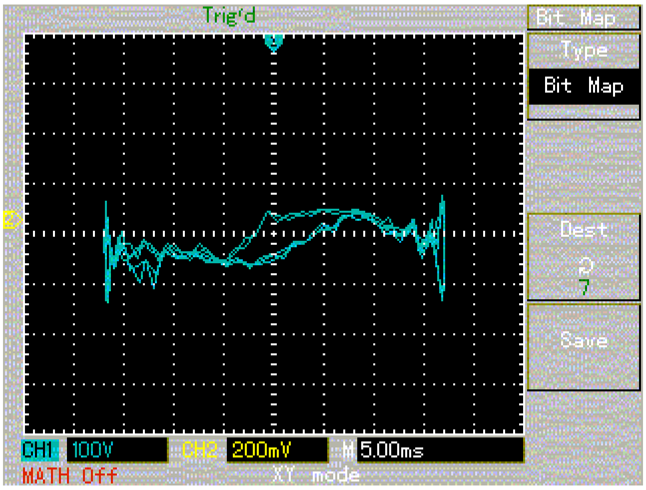
Again, the XY plot now shows the losses in the core are now back to just the hysteresis ones, and that the addition of the filter prevents the offset load from affecting the sample transformer.

Live mains tests

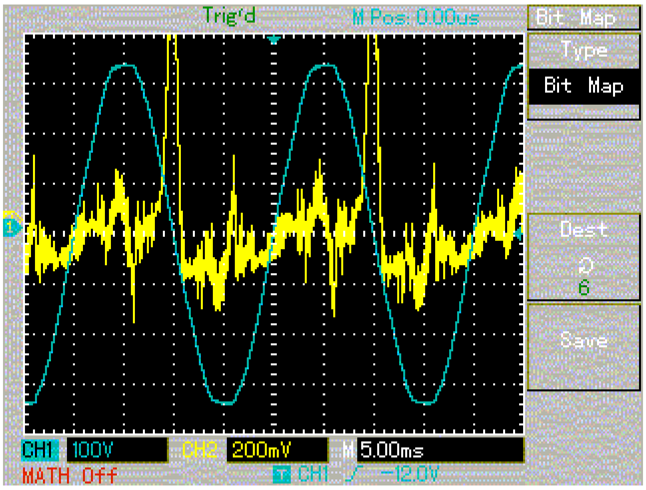
After the tests with synthesised mains sources showed how easy it was to detect the presence of asymmetric loads on the supply. Another series of tests were performed using the wall supply in the workshop. In this case the asymmetric load was supplied by the use of the heat gun normally used for shrink tubing. When running on the half power setting, it used an internal diode to reduce the power to the heating element in just the same way as the diode and resistor was used in the initial tests.



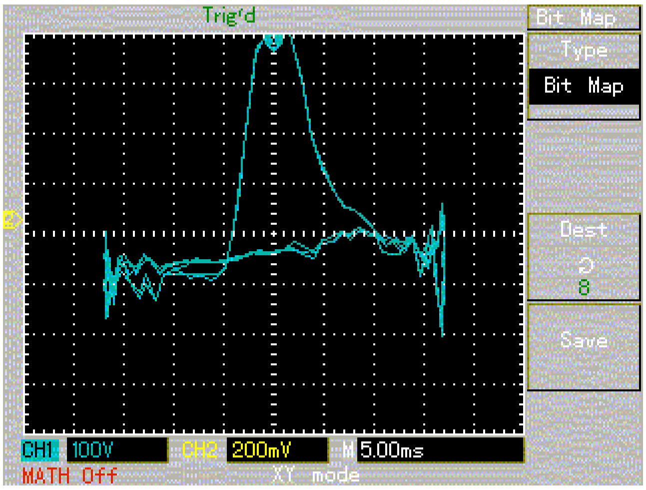
This is the display of the system with no load, just the idle current flowing in the transformer core. The first thing to notice is the voltage trace is far from the ideal sine wave of the earlier tests. Also worth noting is that the trace of current has far higher levels of noise. So much so that the noise contributes far more to the idle current than the underlying hysteresis loss that the previous controlled tests demonstrated. The scale of current trace has also been altered to reflect the higher levels of current. The author was unsure at this point if the underlying asymmetric problems could be observed in the midst of the level of noise.



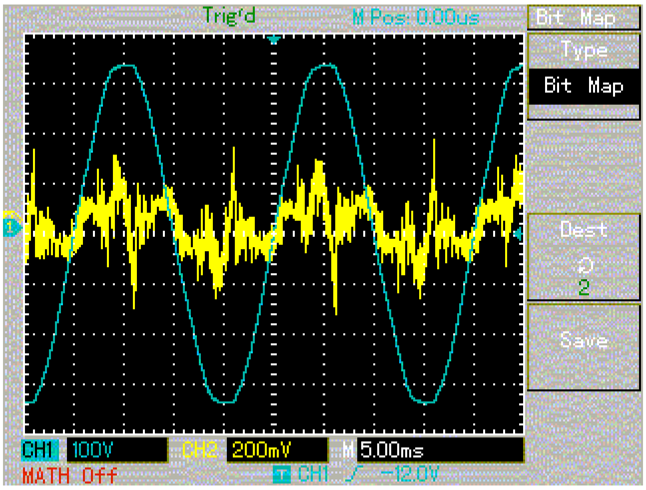
Again the corresponding Voltage/Current phase display. The hysteresis curve is still visible, but is now obscured by the high noise level, and the distortion of the sine wave at its peaks.



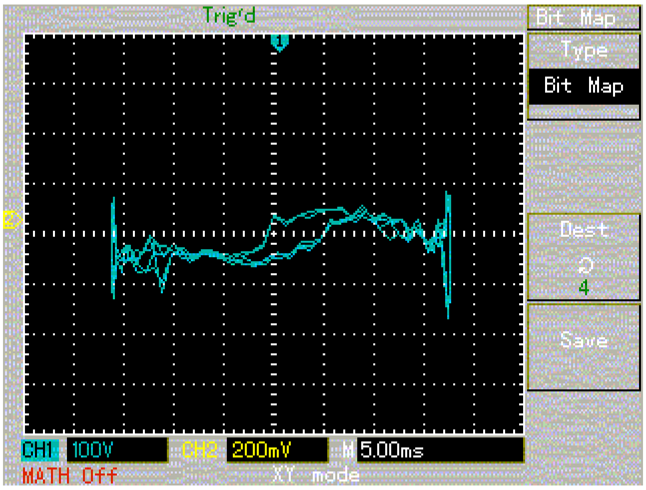
Turning on the heat gun instantly removed any doubt as to if the effect of the asymmetric load would be measurable. The same peaks are seen as were found in the controlled tests.



And again in the phase display, the signature curve is seen as before.



Once again, inserting the corrective filter into the supply, with the heat gun running, restores the display showing that the effect of the uneven load is removed, and the display is restored to its off load state.



Again, the phase display is restored as before.

Sightings in the wild

While the above tests using live mains were being set up, it was seen that "events" happened to the mains supply that caused exactly the type of curve that we have been creating by intentionally applying unbalanced loads to the supply. These fluctuations were only of a few seconds duration, but it was noticed that as the display shifted from the balanced to unbalanced state and back again, this was accompanied by audible buzzing from the transformer under test. As the transformer was under no load from its secondary, the noise was a clear indication that the variations on the line were causing the core of the transformer to saturate.

The fact that the same changes in the measured loss curves were found when the test was in a steady state was a clear indication that the test process was showing a condition that actually happened in normal use, and so was not just a side effect of the test conditions.

The disturbance was never seen with the filter in place, but as its possible that the events didn't occur with the filter in place, to be certain that the filter was removing these real live symptoms as well as the ones created on demand, it will be necessary to set up two identical test sets, one with the filter, one without, and then to observe the effect at the same time on both sets.

Test Summary

The loading circuit only applied an extra load of 23ma to half the waveform, producing far smaller imbalanced in the resultant mains supply than those that can be found in real mains supplies. This however was still enough to clearly see the effect on the core losses in the sample transformer. The corrective effect of inserting the filter into the circuit was also clearly and repeatable shown. Further, having seen identical behaviour when monitoring live mains, it seems certain that the test was simulating a real process.

What the test has not attempted to show is the correlation between the application of the filter with subjective listening results when used with audio equipment. These tests will be carried out, but having objectively devised a test protocol to the effect, and found ways to create as required; it should be possible to devise a listening test procedure that will show what correlation there is between objective measurements and subjective listening impressions.

The corrective effect of the filter was so striking, that the author fears that the reader may believe that the displays shown after the filter are actually just those with the offset load removed. But the test setup is simple and the results are easy to reproduce (with the earlier safety point's clearly in mind), so if any reader wishes to reproduce the tests, the author is happy to enter into correspondence on the subject.

All the tests were carried out by the author Nick Gorham, using the filter circuit developed for Mains Cables-R-Us by the author.