

## APPLICATION NOTE - 012

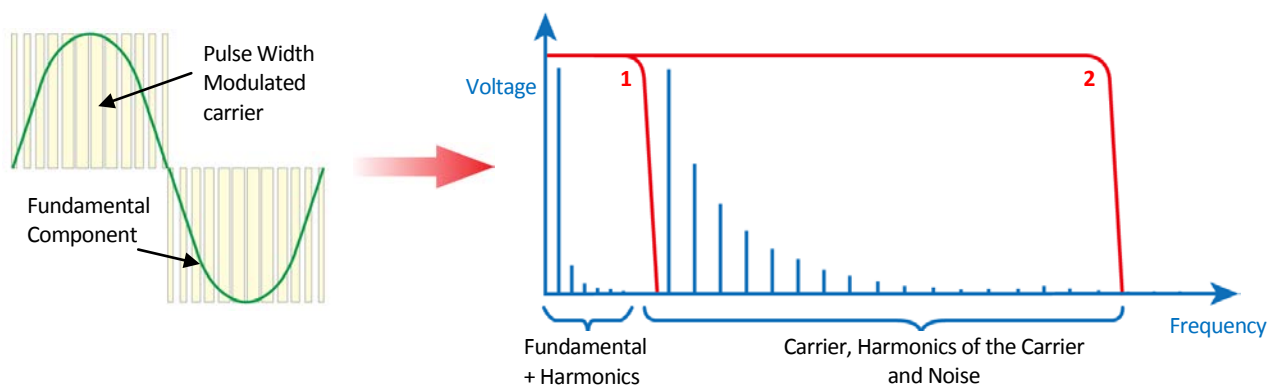
### Innovative shunt design techniques optimise power measurement accuracy

#### Introduction

Rapid developments in power conversion technologies combined with a need for better product efficiency places increased pressure on the design and test engineers of modern power electronic systems to more accurately quantify the true value of electrical power.

This need focuses attention on the accuracy of power measurement instruments and it becomes clear that complex power characteristics associated with modern power conversion techniques require high frequency performance that is beyond conventional analyzer design.

To illustrate this need, we can consider the voltage signal associated with a PWM inverter drive:



Clearly, if we wish to accurately quantify total power, we need to include all frequency components of the signal. This may at first appear straight forward since many power measurement instruments offer an appropriate frequency range but in most cases, high accuracy of power measurements is only achieved over a limited frequency range. This is illustrated by response line 1 which represents the typical high accuracy range of many power analyzers compared to response line 2, which represents a power analyzer that maintains high accuracy over its complete operating frequency range.

#### Hardware design

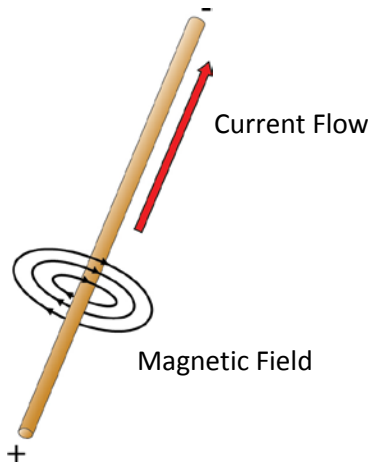
One of the main challenges in achieving good accuracy in power measurement over a wide frequency range is the hardware design of the voltage and current inputs. For the voltage input, the frequency response is largely influenced by parasitic capacitance and for the current input where a low resistance shunt is used; the frequency response is largely influenced by parasitic inductance.

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It follows that the wideband performance of a power measurement instrument can be optimised by minimising the capacitive reactance of the voltage input and the inductive reactance of the current shunt.

Usually, the greatest challenge for a precision AC power measurement instrument is to achieve a low inductance current shunt. This is particularly difficult in power analysis products because the shunt resistance needs to be low so that the shunt power dissipation and circuit burden are minimised. However, since the parasitic inductance of a component is a function of its geometry, it follows that a shunt of any particular physical geometry will have a greater phase error as the shunt resistance is reduced because the same inductance will represent a greater proportion of the total impedance.

Since inductive impedance increases with frequency, it also follows that the error associated with parasitic inductance increases with frequency.



Here we can see the basic phenomena where current flow through a conductor results in a rotating magnetic field. The presence of this field represents an inductive component.

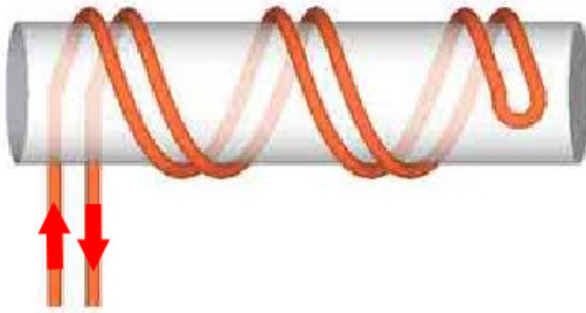
Recognising the error in magnitude and phase associated with the parasitic inductance of resistive shunts, power measurement instrument designers use a range of techniques to minimise magnetic field and therefore the level of inductance.

### Conventional solutions

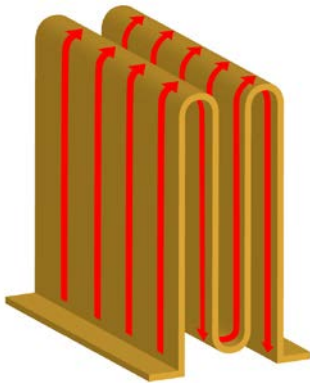
In order to reduce the inductive component of a resistive shunt, various techniques are used to achieve magnetic field cancellation, all with the objective of achieving of equal and opposite current flow in adjacent paths.

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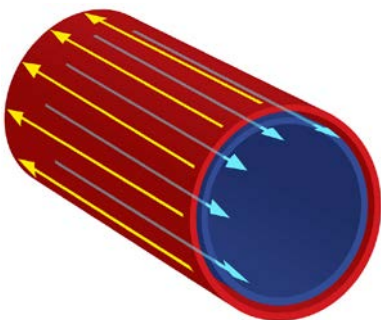
Here we give examples that illustrate commonly used techniques:



Axial resistor with parallel wound resistance wire.  
 Here, the orientation of resistance wire on a tubular former gives some field cancellation due to opposing paths of the forward and return current flow.



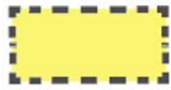
Wave folded resistance foil.  
 Here some field cancellation is achieved by the opposite current flow in adjacent foil planes. This technique has an advantage over the axial design of superior natural cooling due to an increased surface area.



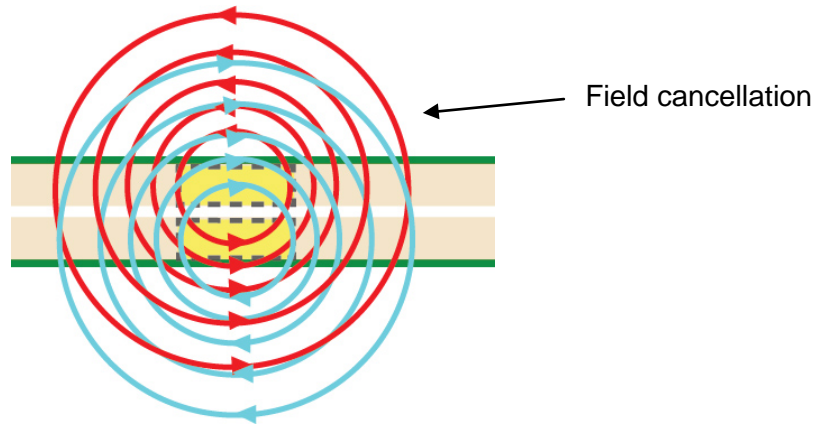
Coaxial shunt.  
 Here, the Input and Output connections are made at one end of the concentric tubes and there is a link at the other end to connect the flow and return layers. This design achieves superior field cancellation to the axial or foil techniques. However, the mechanical complexity of this design makes it an expensive solution

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If we consider one flow and one return path in the two layers of a coaxial shunt looking from one end of the shunt, we can see a very effective cancellation of the rotating fields.



Forward and Return current path in outer and inner tube



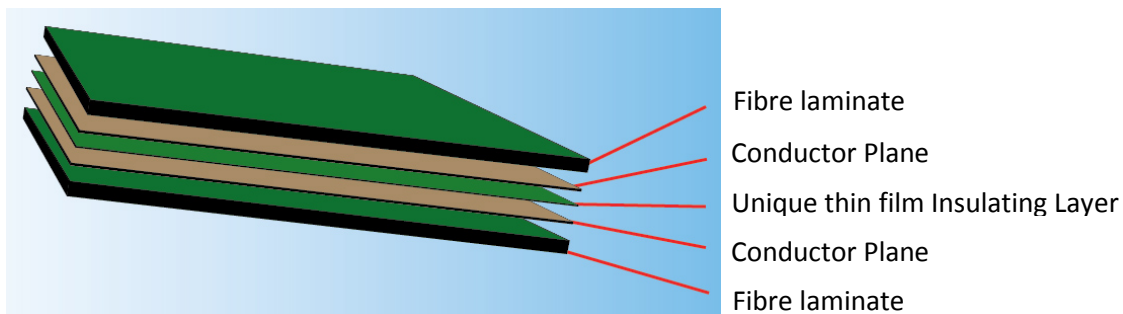
### An innovative solution

While the field cancellation of a coaxial shunt design is good, the physical size, mechanical complexity and cost of this technique are prohibitive and therefore this technique is not commonly used.

However, Newtonson4th Ltd based in the UK has developed and perfected a design that achieves field cancellation equal to that of the best coaxial shunt while maintaining a manufacturing cost that is viable for use in commercial power analyzers.

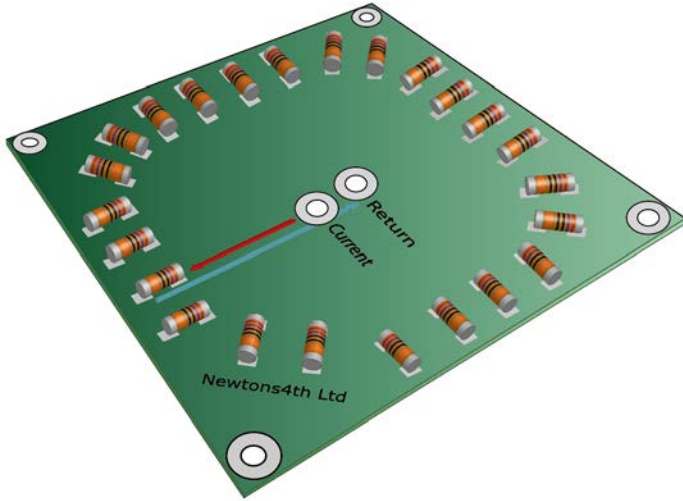
Since the main cost associated with coaxial designs comes from the costly metals, machining and assembly of a shunt that incorporates three dimensions, the objective for this new design was to achieve optimum field cancellation on a flat circuit board assembly.

The board would require thicker conductor planes than conventional circuit boards combined with a thin insulation layer between the conductors to optimise field cancellation and outer laminate layers to provide mechanical strength.



Innovative shunt design techniques optimise power measurement accuracy	525-012	Issue 1
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Using centrally connected feed and return paths leading to surface mounted resistors that are positioned to the outer edge of the board, the optimum balance of resistor power sharing and field cancellation are achieved.



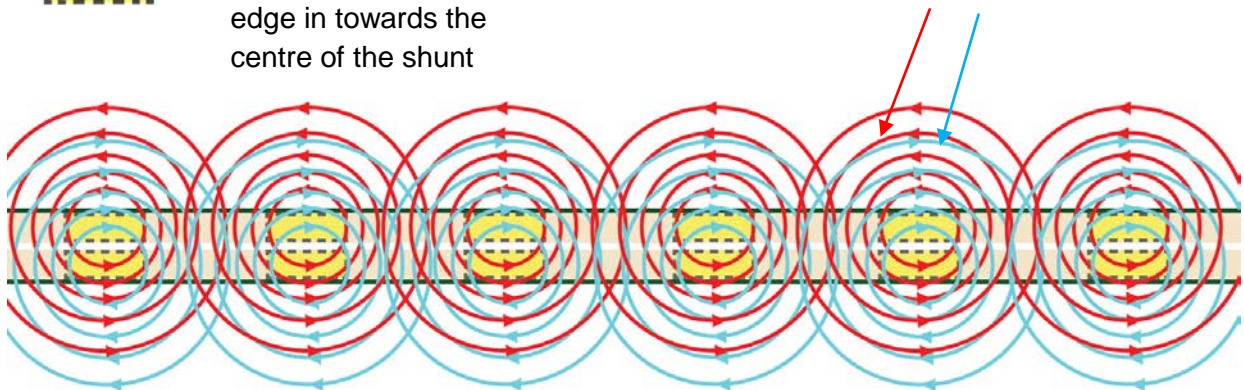
Here, a simplified version of the board design shows the forward and return current paths to precision low thermal drift surface mount resistors.

This layout combined with low ppm resistors and airflow across the horizontal plane result in minimal temperature change over the complete operating current range.



Current path looking end on from the outer edge in towards the centre of the shunt

Cancellation of magnetic field from forward and return current flow

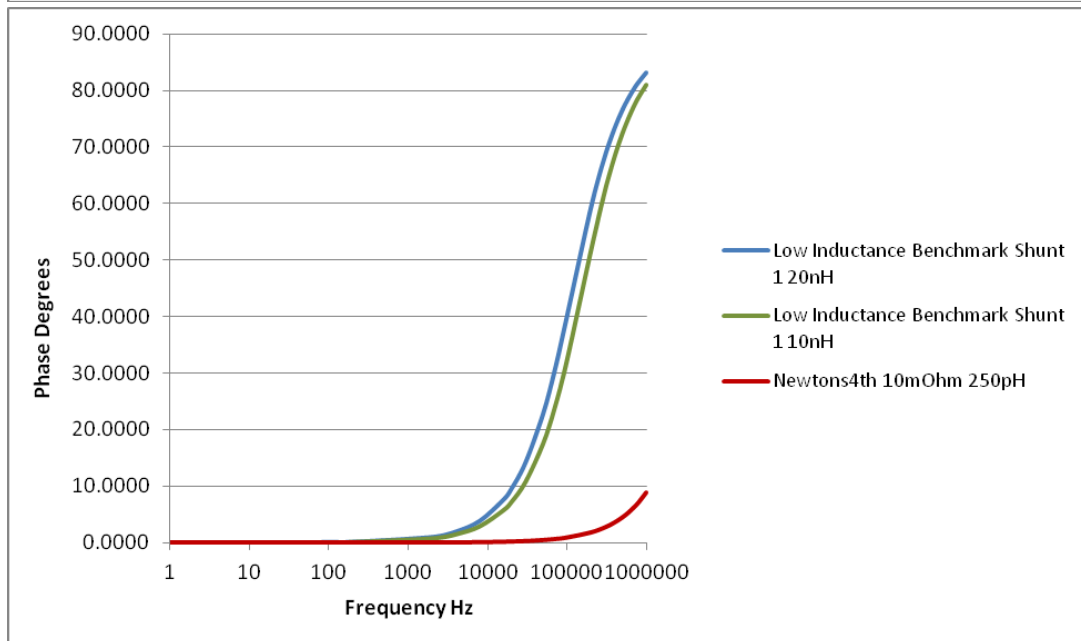
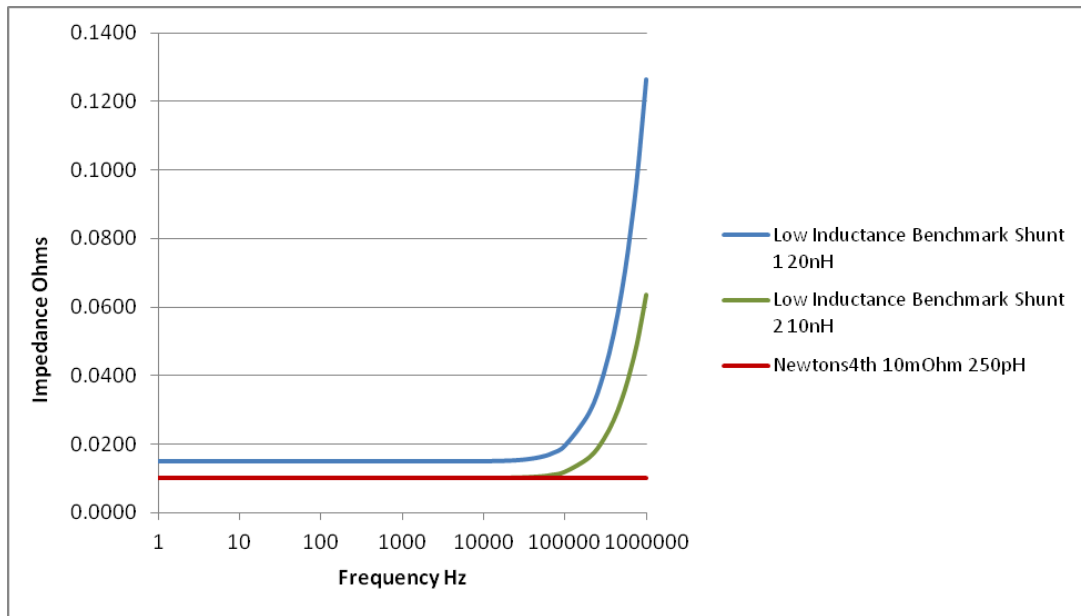


### Impedance and Phase comparisons

In order to understand the Impedance and Phase response of this new design relative to other commercially available low inductance resistive shunts, we follow with a comparative table showing the nominal resistance and inductance of three models including the new design from Newton's4th Ltd.

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Shunt	Resistance	Inductance
Low Inductance Benchmark Shunt 1	15mOhms	20nH
Low Inductance Benchmark Shunt 2	10mOhms	10nH
Newtonson4th Current Shunt	10mOhms	250pH





## Conclusion

Using innovative techniques in analogue hardware design combined with the latest digital analysis techniques, Newton's4th Ltd's modern measurement instrumentation can meet the needs of the most demanding power applications.

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3<sup>rd</sup> January 2012

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