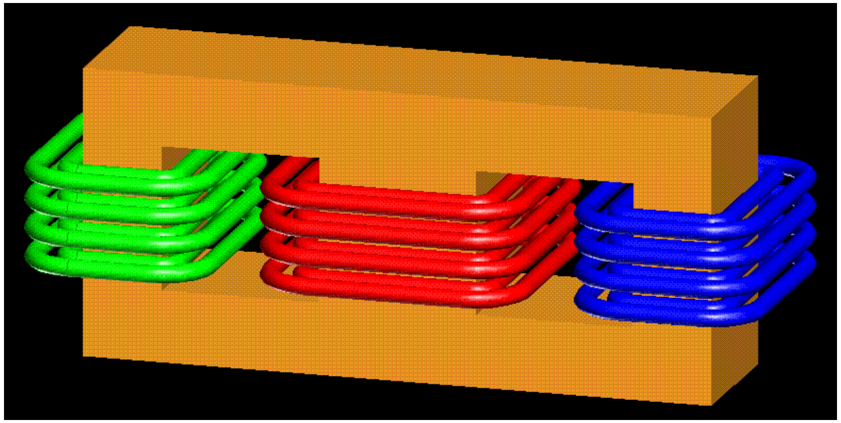
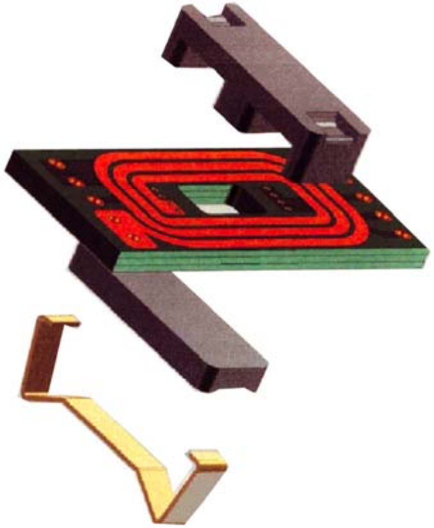
Predicting Total Harmonic Distortion (THD) in ADSL Transformers using Behavioural Modeling





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Outline

Introduction

- ADSL
- Where is the need for the transformer?
- What are the design Issues?

Modeling and Simulation

- Basic Transformer modeling
- Non-linear modeling
- System modeling

Hardware modifications

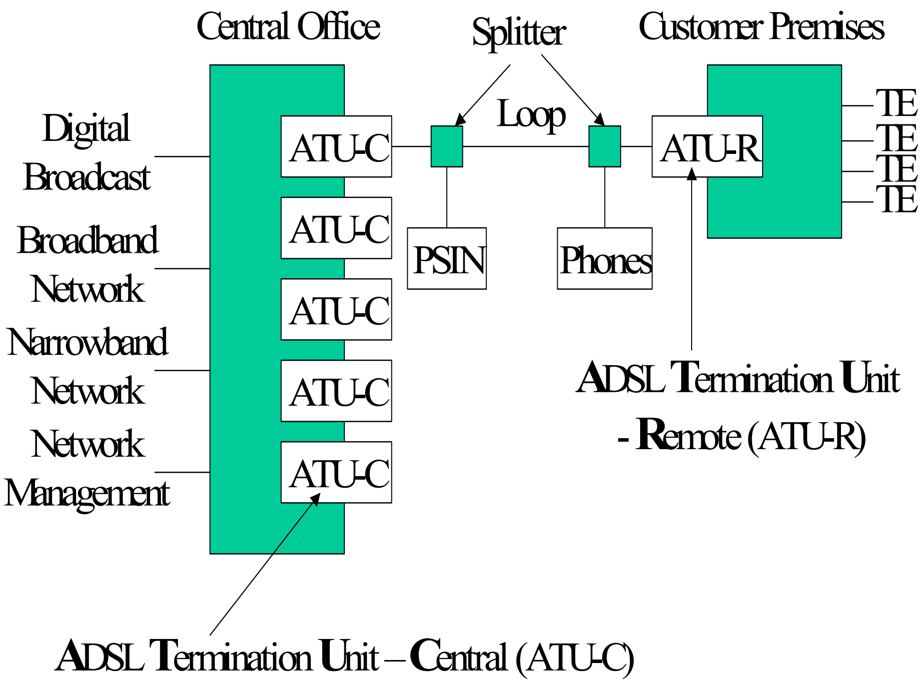
- Planar transformers

Conclusions

ADSL: Introduction

Asymmetric Digital Subscriber Line

- The technology is used as a high-speed modem link with asymmetric up- and down-stream data rates
- The technology is important because it uses the existing standard POTS network infrastructure
- The mechanism only requires an ADSL modem at the local telephone exchange (CO) and a similar modem at the customer site (CP)

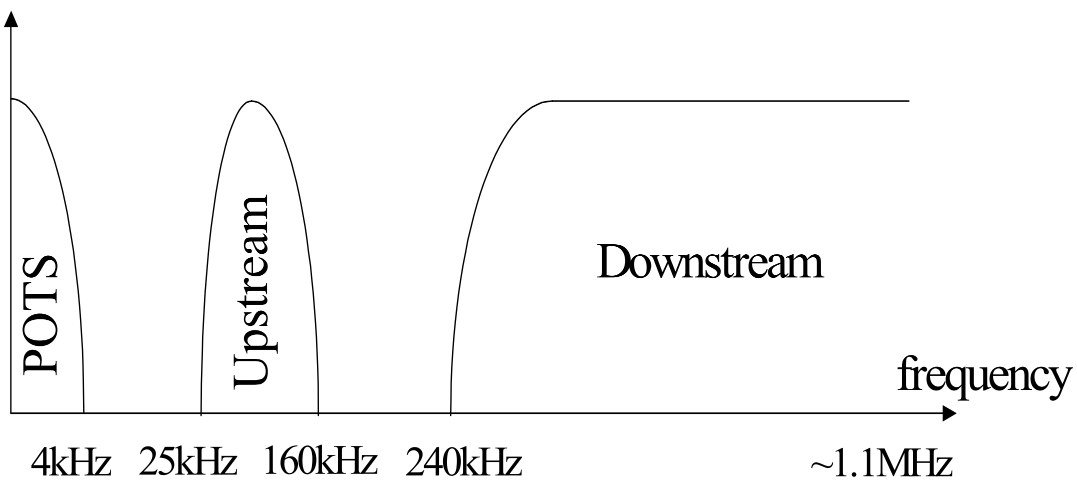


ADSL Modulation Scheme

ADSL is based on a broadband modulation scheme

- multiple carriers placed at 4.3125kHz intervals
- With 256 carriers a 1.1MHz bandwidth is required
- These sub-carriers may also be referred to as sub-channels.

ADSL co-exists with POTS



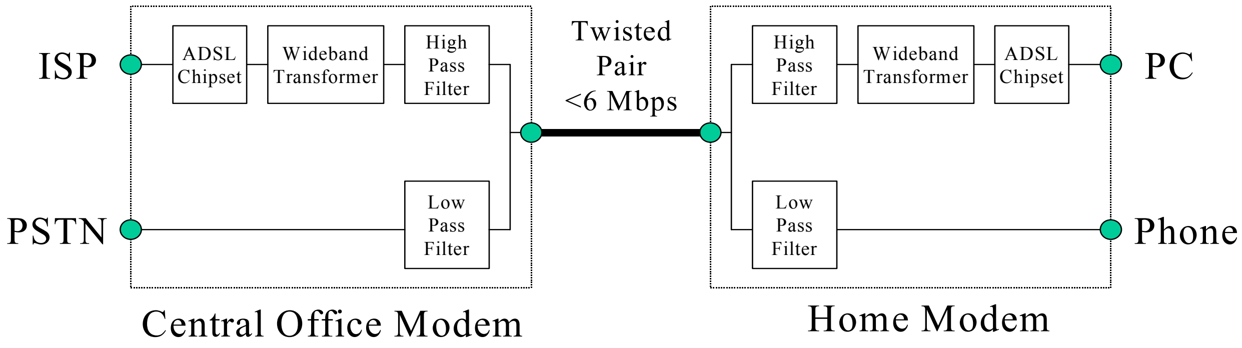
ADSL Analog Interface

The signals are transmitted using a form of QAM, either

- Carrier-less Amplitude/Phase Modulation (CAP)
- Quadrature Amplitude Modulation (QAM)

The modulators and demodulators are interfaced to the line with:

- Channel splitting filters
- Impedance-matching wide-band transformers



ADSL transformer design issues

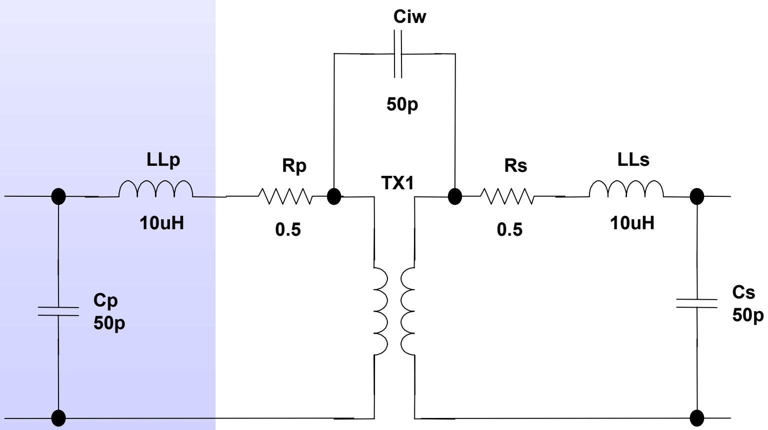
The ADSL transformers have several basic requirements:

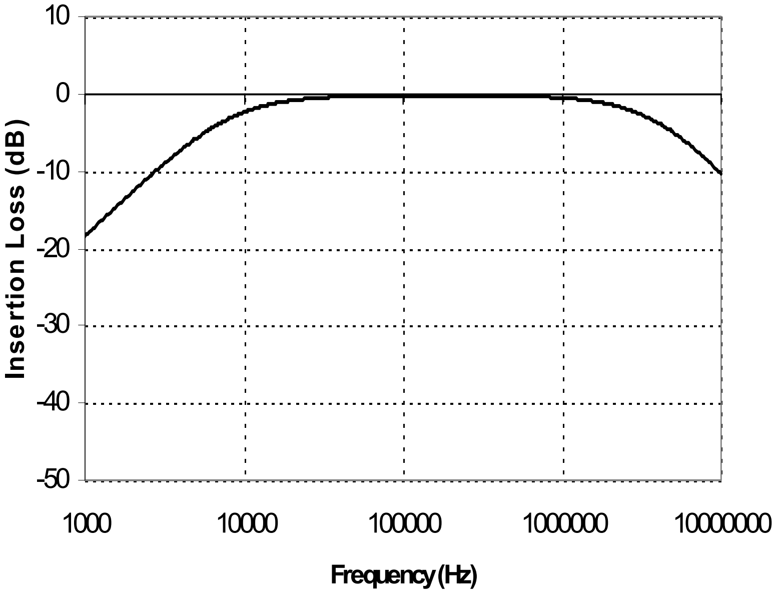
1. **Wide Bandwidth**
    1. This implies low loss, low leakage and low capacitance
2. **Low Insertion Loss**
    1. This implies low resistance and loss
3. **Low Distortion**
    1. This implies good linearity
4. **Compact Size**
    1. There is a design trade-off between distortion and size

Modeling Insertion Loss

We can use a simple linear model, with accurate parasitics to predict the insertion loss over a wide frequency range

This is well understood and works reasonably well





Predicting Distortion

Distortion is a result of non-linearities in the transformer

The source of the non-linearities is mainly from the ferrite core of the transformer

Distortion is quantified for ADSL system designers using the Total Harmonic Distortion Measure (THD), which is closely related to the Signal to Noise Ratio (1/THD)

THD in this context is usually calculated using:

$$THD = \frac{\sqrt{\sum_{i=2}^{5} V_i}}{V_1}$$

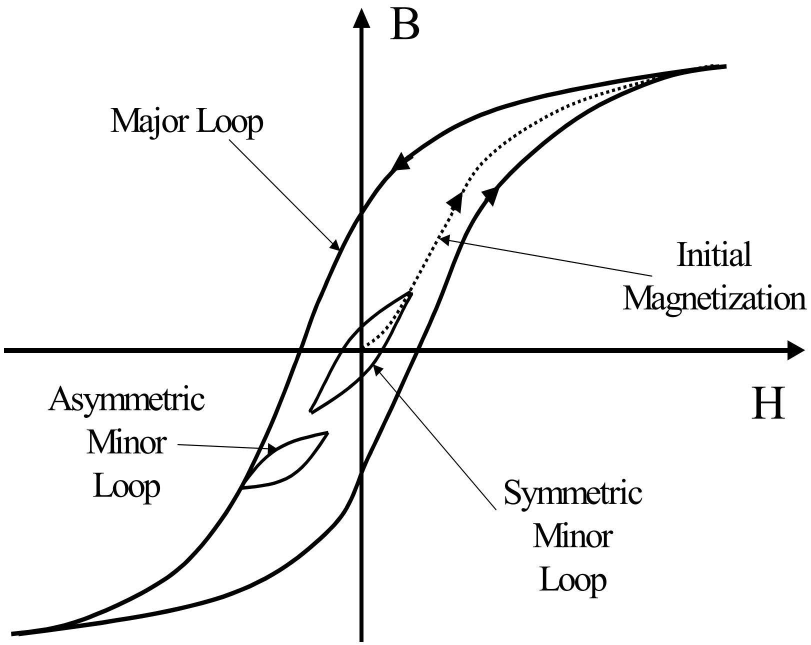
Where:

Vi is the harmonic (i)
V1 is the fundamental

Ferrite Material Hysteresis

Ferrite materials exhibit some form of hysteresis

- **The trouble with signal transformers is that a convenient major loop cannot be assumed**
- **The loops may be:**
  - Assymetric
  - Minor
- **Modeling these effects is actually very difficult to accomplish accurately, as the standard models assume a major loop**

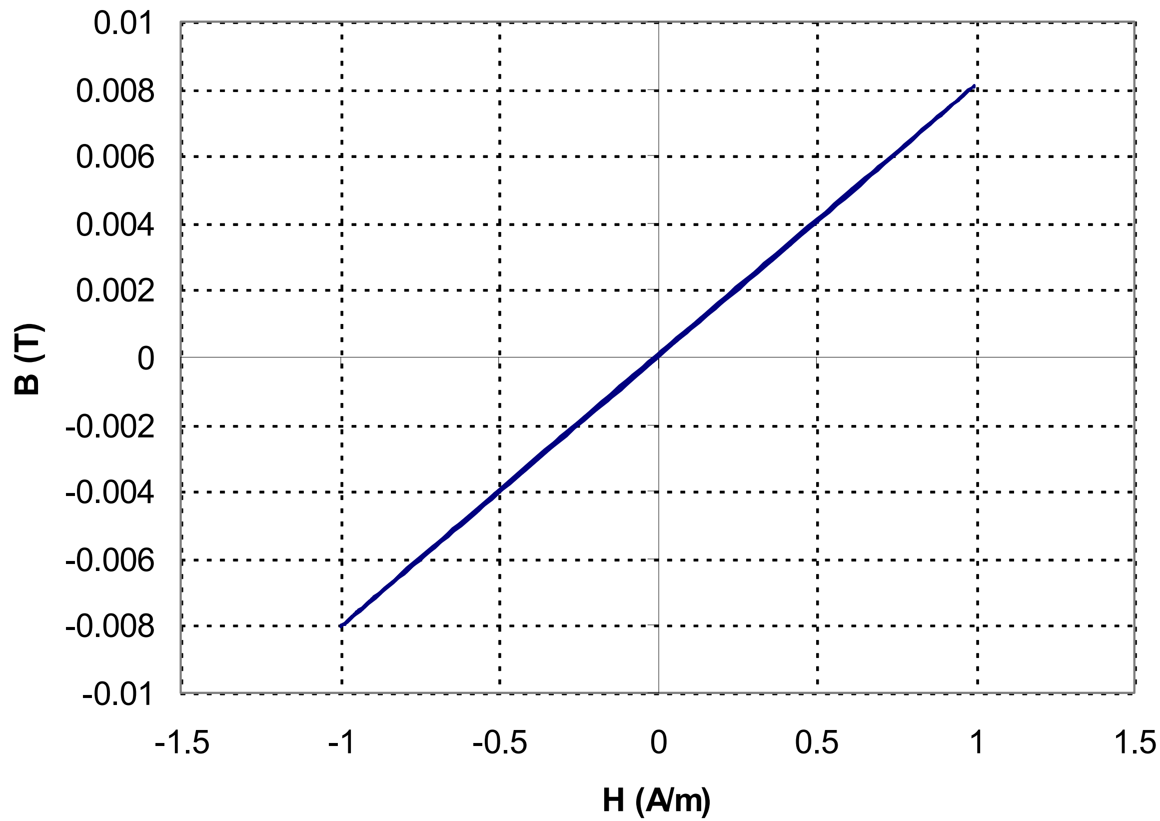


Different Loop Types – Small Minor Loop

Linear

No Losses

Minimal Distortion

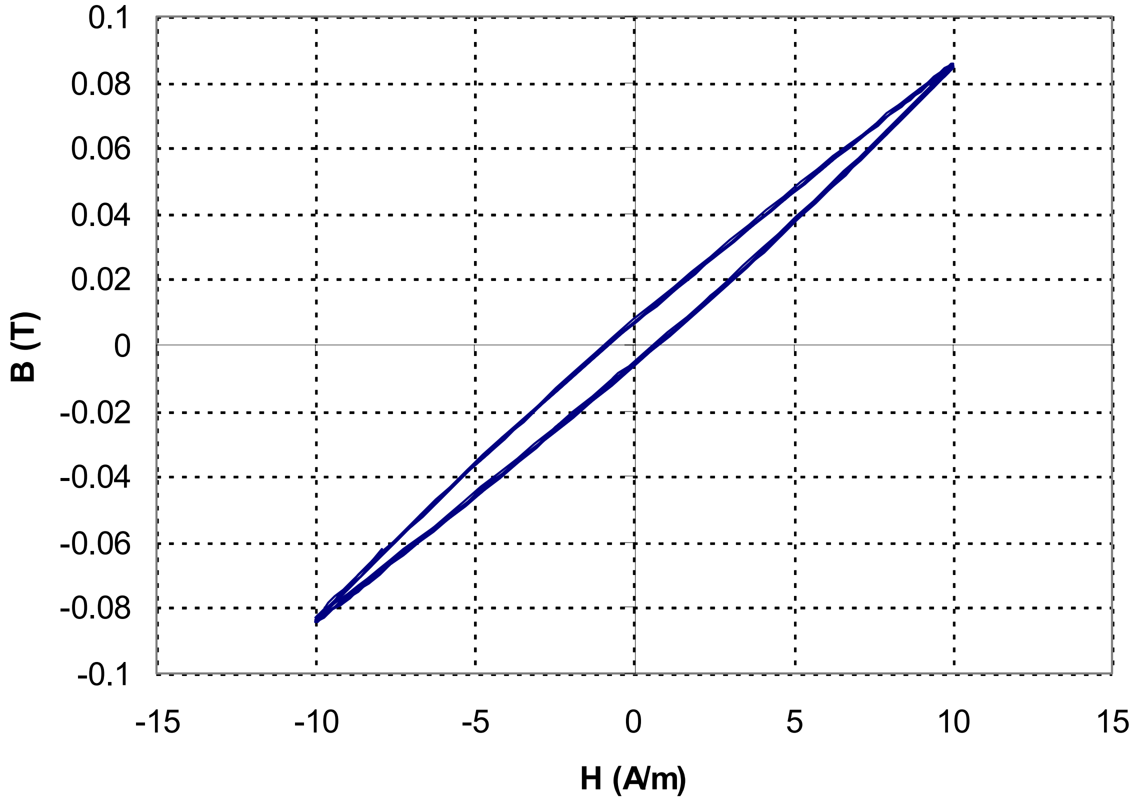


Different Loop Types – Medium Loop

Small Hysteresis

Low Losses

Minimal Distortion

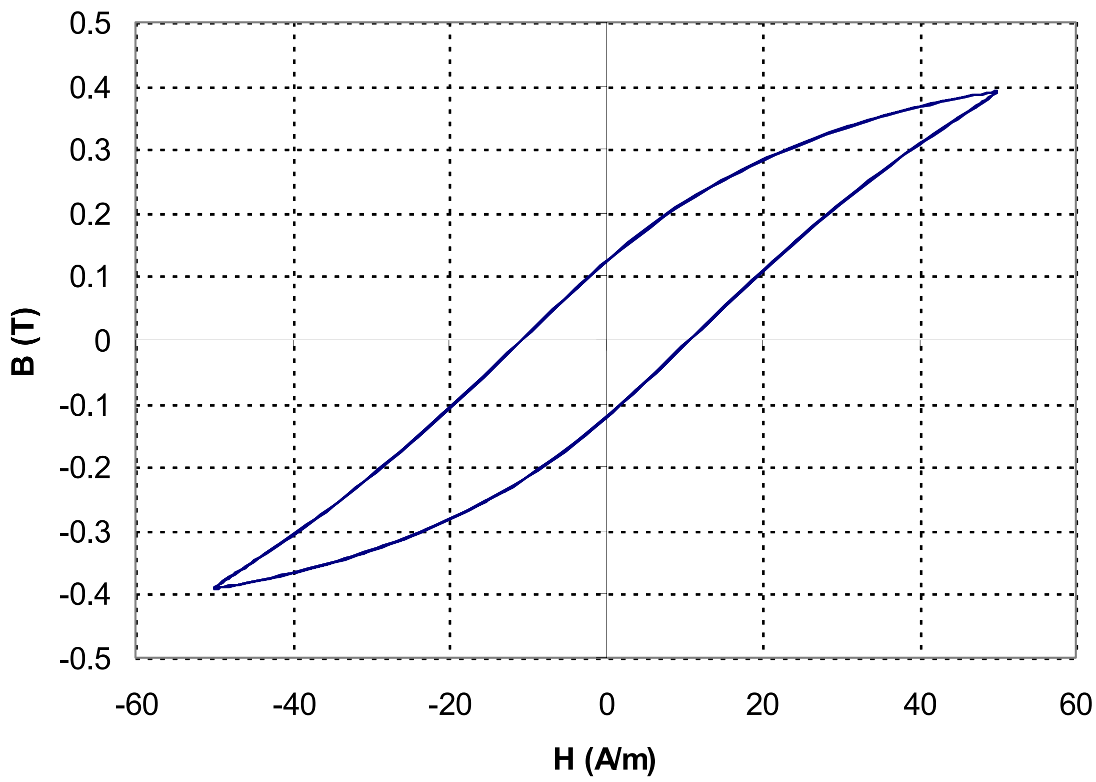


Different Loop Types – Major Loop #1

Significant Hysteresis

Significant losses

Large Distortion



Different Loop Types – Major Loop #2

Significant Hysteresis

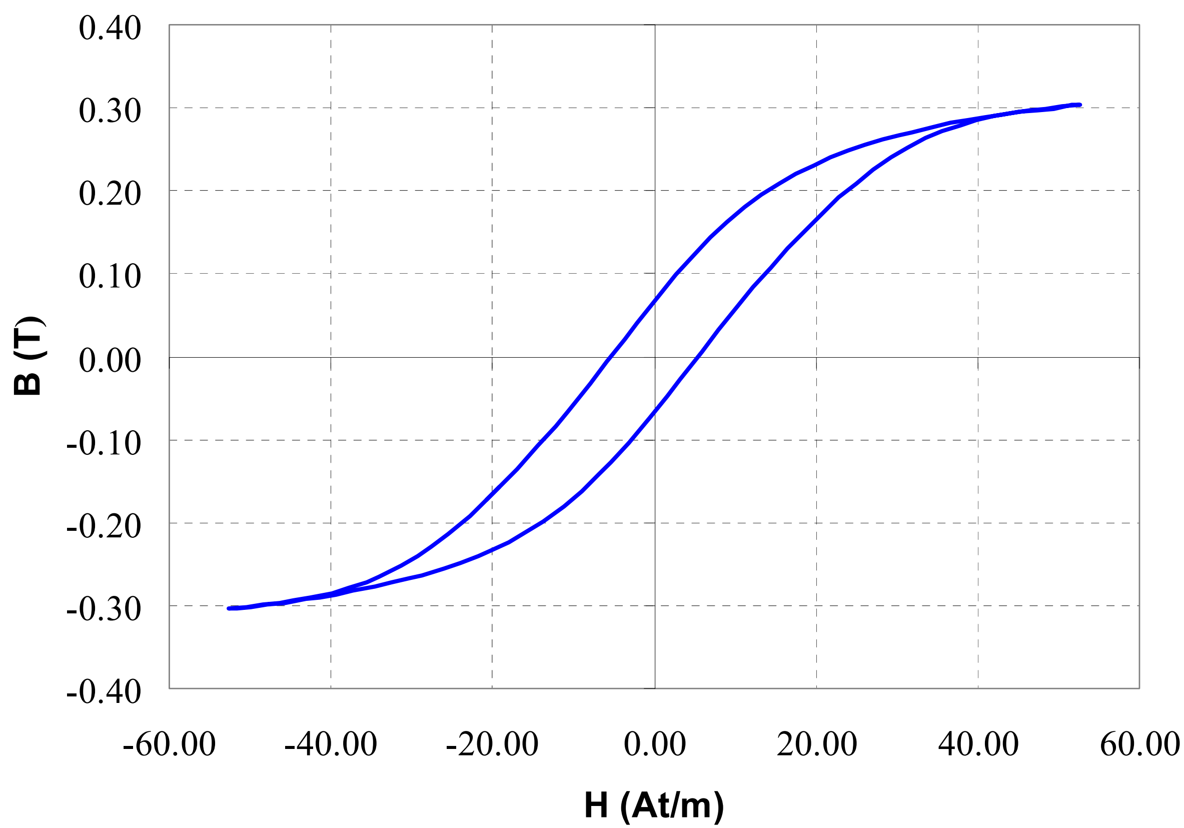
- Slightly reduced

Significant losses

- Relatively smaller

Large Distortion

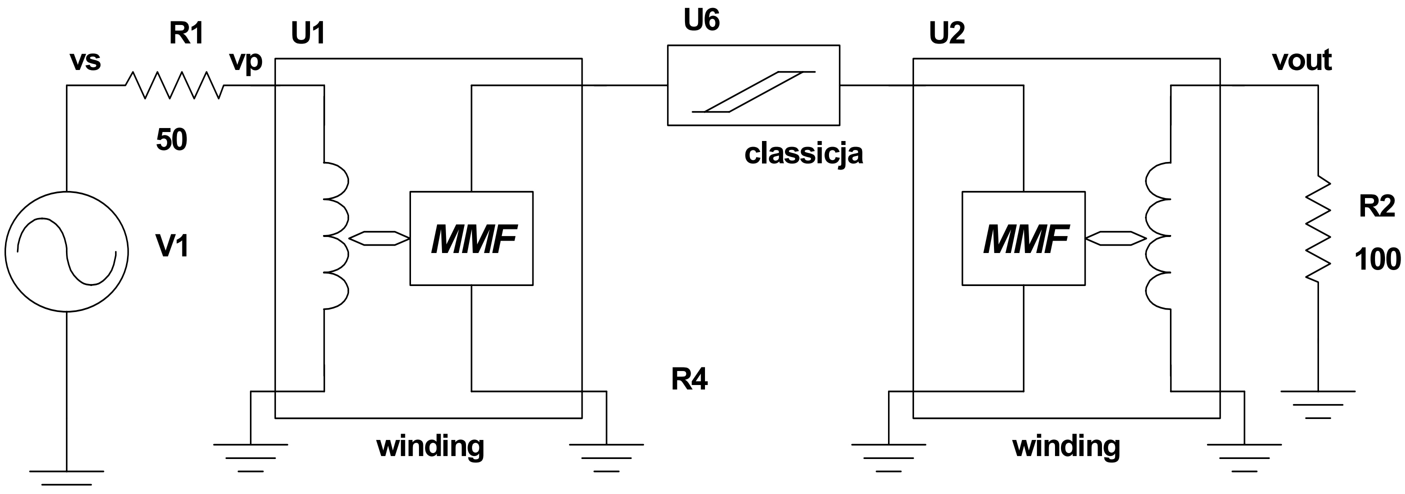
Early Closure



Mixed-Domain Model

The approach used in this paper was to use a mixed-domain model of the transformer, with a modified Jiles-Atherton core model

- Single Lumped Model



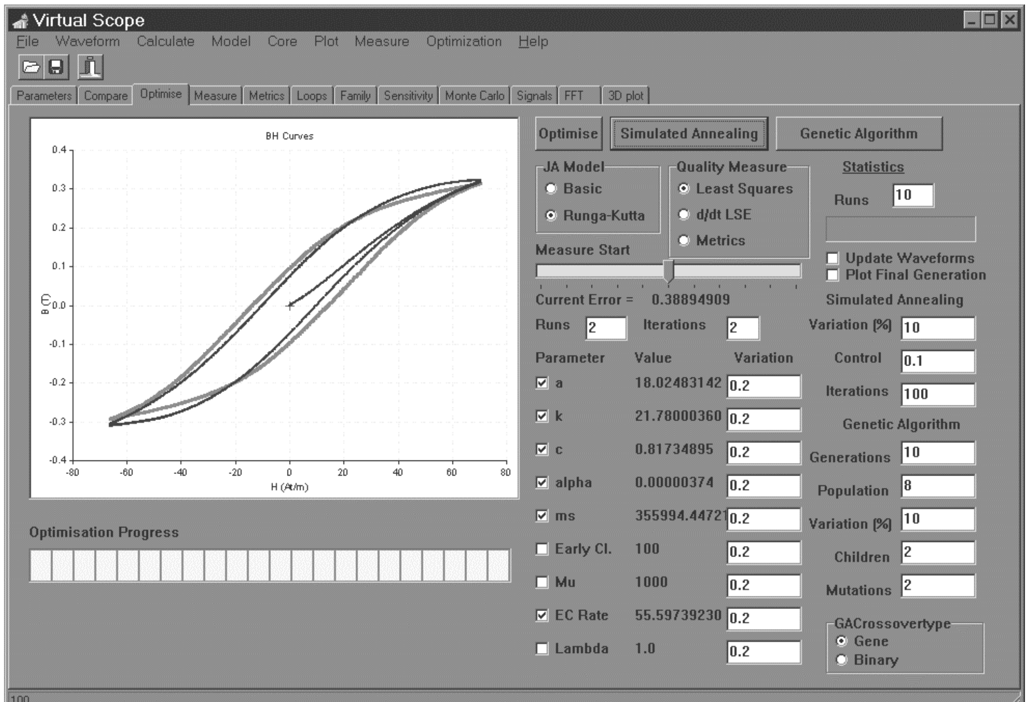
Handling Minor Loops

There are three approaches to dealing with minor loops

1. Characterise the model over a wide range of operation
   1. This is OK, but means accuracy is compromised for each specific case, in favour of a generally accurate model
2. Characterise for only minor loops
   1. This works well, but is very specific
3. Modify the model to change behaviour for minor loops
   1. In theory this sounds good, but the existing models do not implement this capability. Plus, the models need a-priori knowledge of turning points, which leads to innacuraccies.

Characterisation Software

To handle multiple loop optimisation, software has been developed to take measured BH curve data and extract parameters that best fit all the curves imported from different signal levels



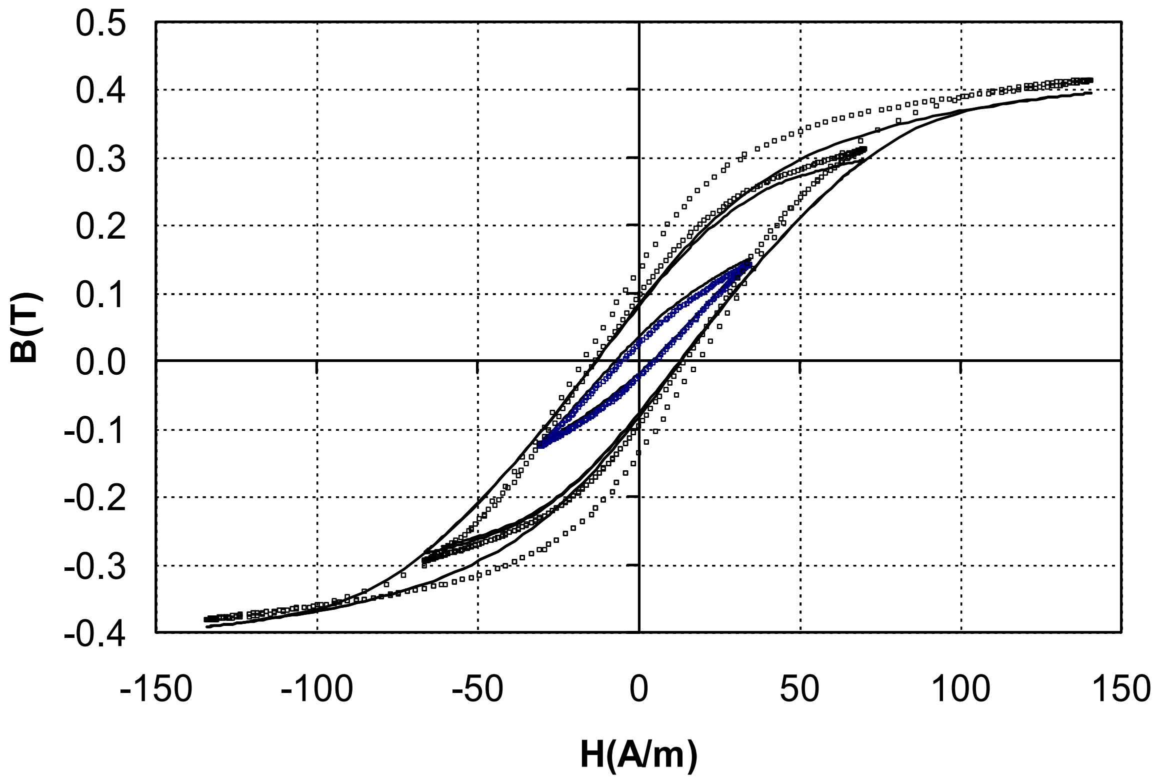
Characterised Waveforms

Three Measured Loops

- Major
- Medium
- Minor

Optimiser Settings

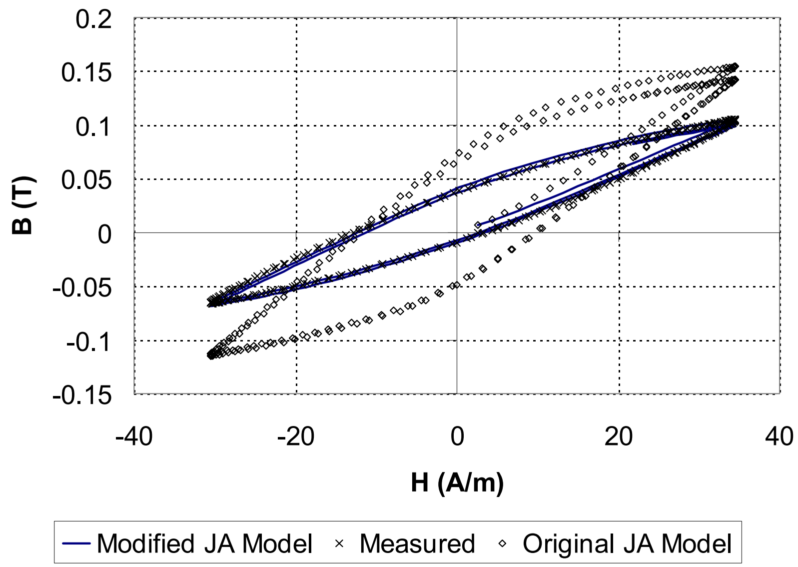
- 3 loop fit
- Equal weighting
- Genetic algorithm



Modifications to the Jiles-Atherton Model

Modifications were also made to the original Jiles-Atherton magnetic model to improve the minor loop modeling, basically modifying the behaviour depending on the recent turning points

- **Worked well statically**
- **Less effective dynamically**
- **Poor with arbitrary waveforms**
- **Relies on turning points**



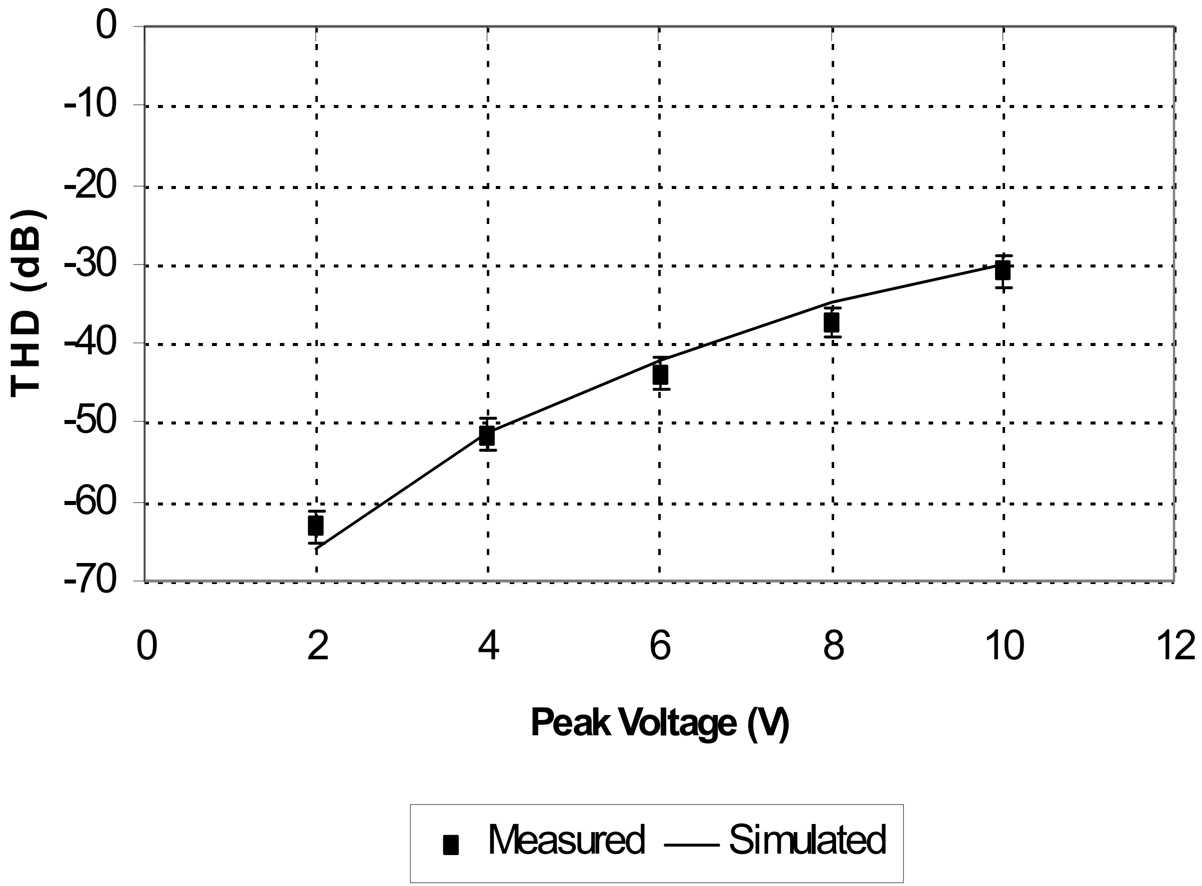
Predicting the THD of ADSL transformers

In practice, there was no need to have overly sophisticated models to predict the performance of the transformer as an individual component, as the standard tests were undertaken at single frequencies at a time.

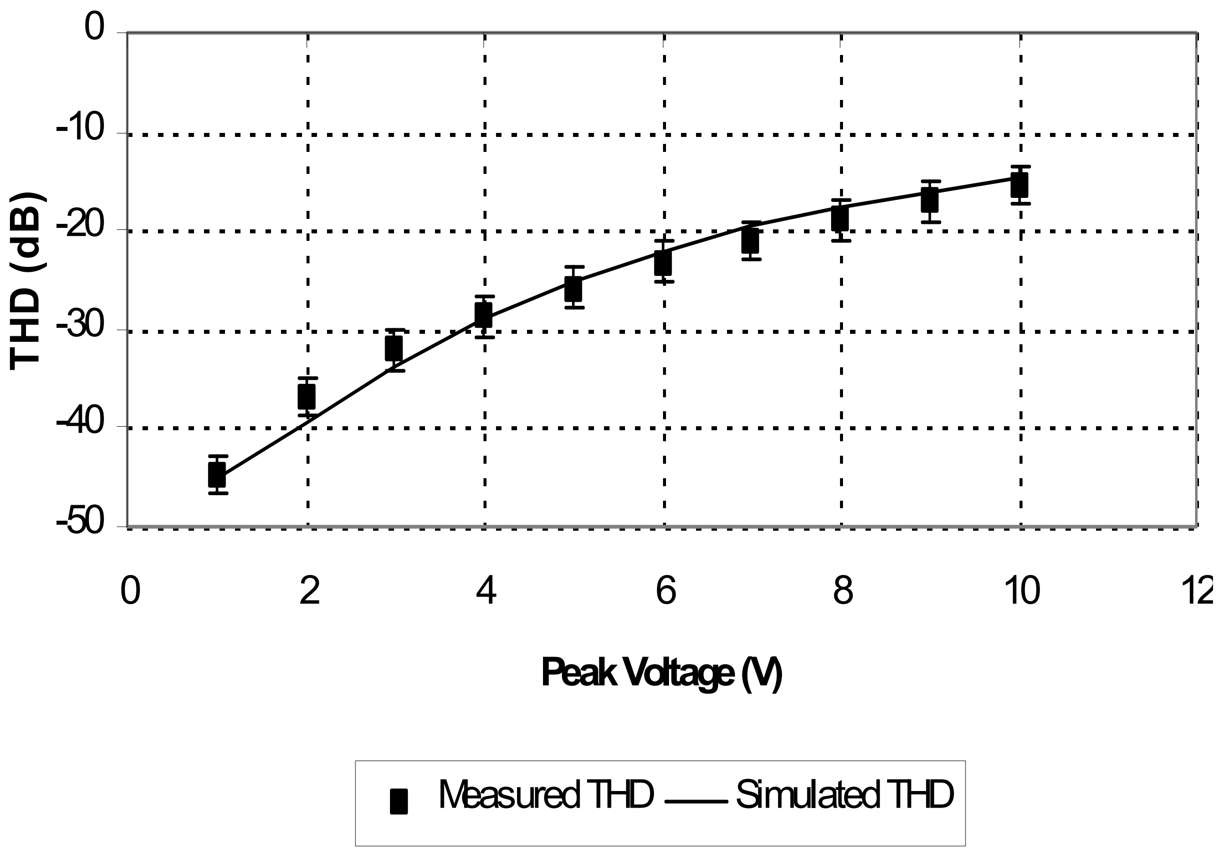
Models were created for standard core types and materials, simulated and the resulting THD compared with measured results using the same components

• Toroid	TN10/6/4-3E5
• Low Profile	E11R-3E6
• Integrated Inductive Component	IIC
• Custom planar Devices	E18/E14
• EP Cores (standard wire-wound)	EP13

Toroid TN10/6/4-3E5



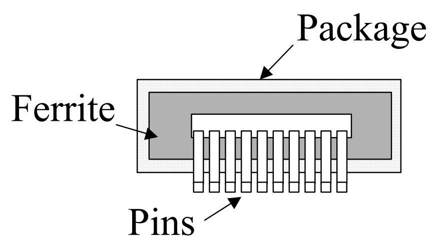
ER11-3E6



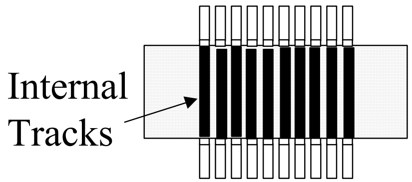
0
-10
-20
-30
-40
-50
THD (dB)
0
2
4
6
8
10
12
Peak Voltage (V)
Measured THD
Simulated THD

Packaging Options

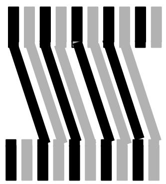
As well as wire wound, integrated inductive components (planar devices) were tested and compared with standard wire wound (EP13) cores:



[a] side view



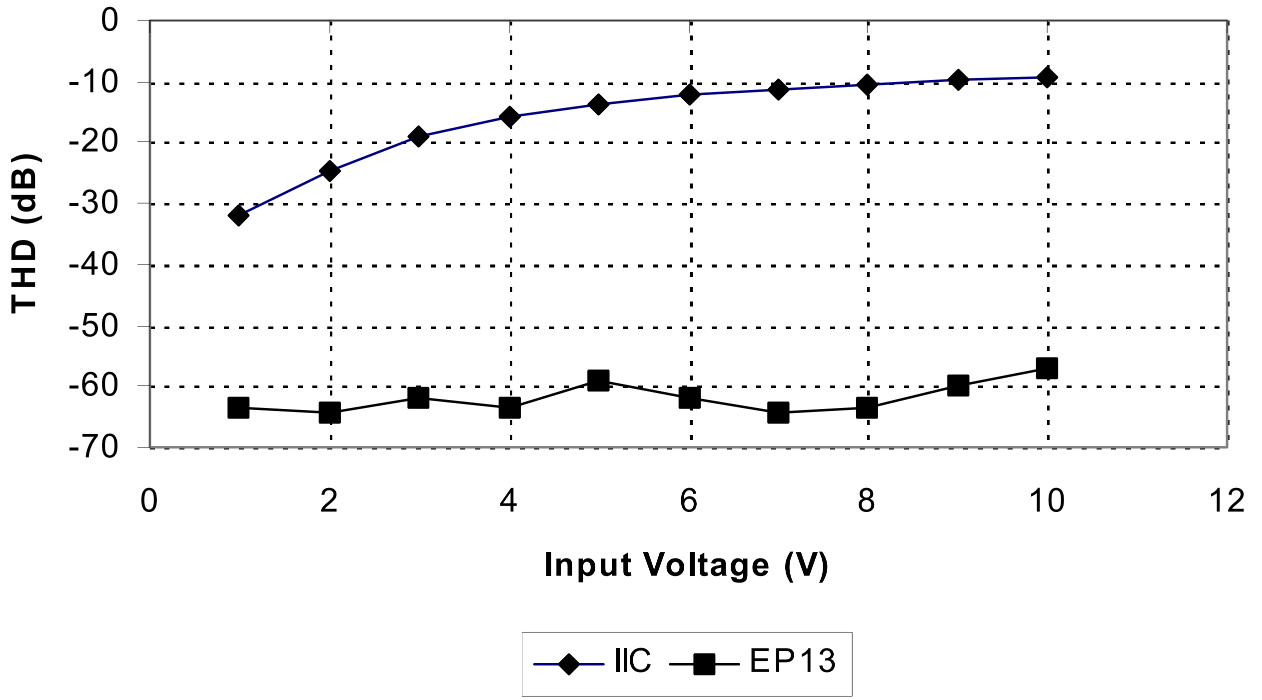
[b] plan view



[c] 5:5T PCB Layout

EP13 and IIC Comparison

The generic planar device is much worse than the EP13 core, and this is predicted by the simulation



Conclusions thus far

Smaller ER and toroid cores are not good enough

- Basically too small – saturate early
- Not enough inductance
- Not enough air gap relative to core size

Integrated Inductive Components not good enough

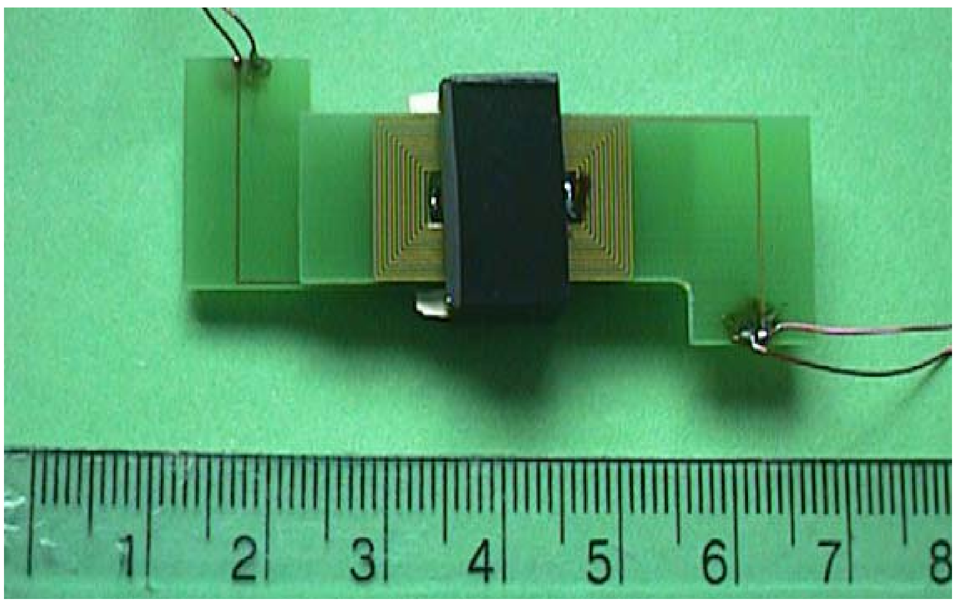
- Too few turns
- No gap

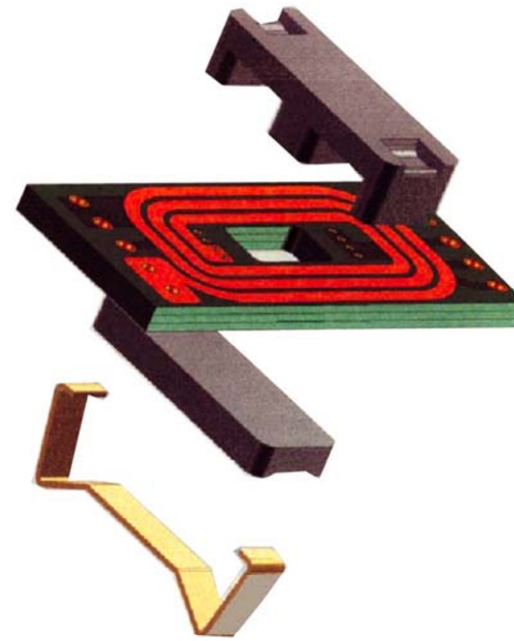
What about custom planar devices?

- More turns
- Custom gap
- Low profile = better density of ADSL modem in exchange

Custom Planar Transformers

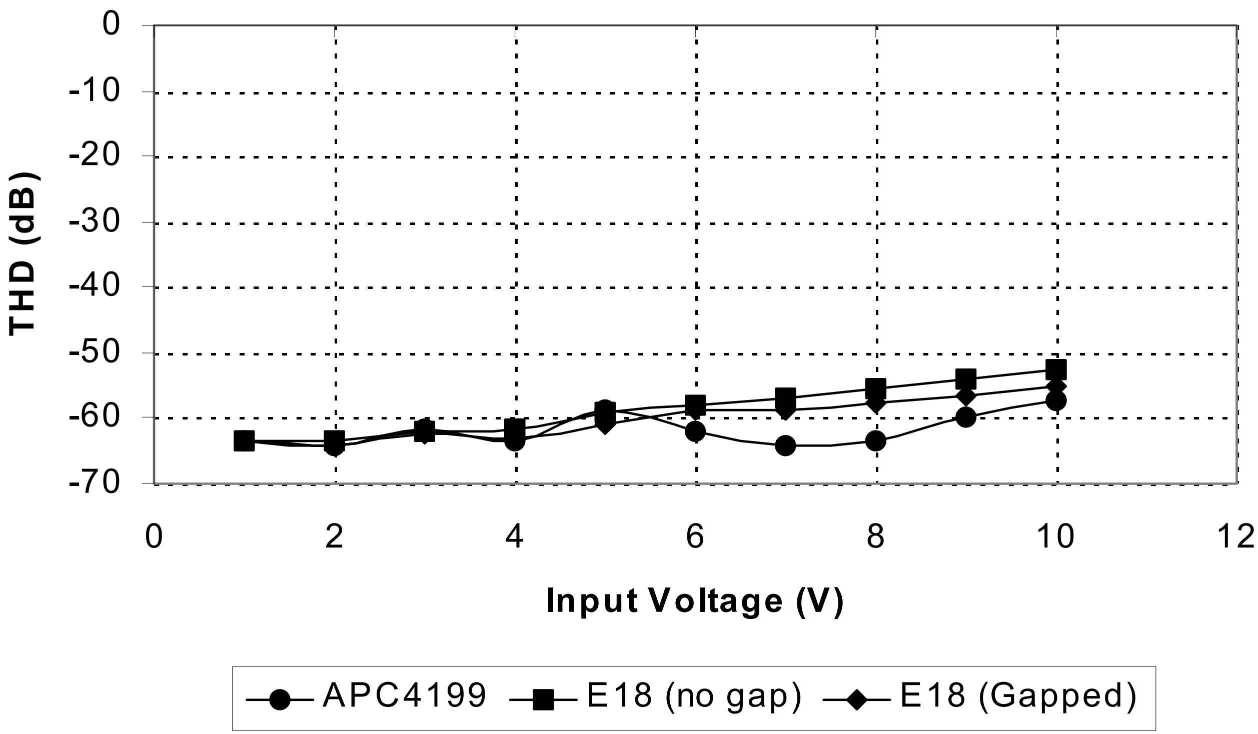
Using a customised planar device, with a large enough core (predicted by the simulation) to ensure low distortion, the tests were repeated using an E18 core





E18 Custom Planar Device

The resulting THD figures were comparable with the standard EP13 wirewound device



Conclusions

Behavioural modeling has been used in a range of ADSL transformers to predict:

- Insertion Loss
- Bandwidth
- Distortion

Simulation has been used effectively to guide the design of the proposed transformers to meet the requirements of the ADSL design context

New planar devices have been implemented that will greatly improve produceability and packing densities in exchanges.