Measuring Telecommunication Transformers

Rapid expansion of the Internet and Mobile Communications has driven the need to transmit digital information at high frequencies. This need has put new requirements on transformer manufacturers and presented new challenges to test equipment designers. This paper explores the changing applications for high frequency transformers, the challenges this presents to test equipment designers and test solutions offered by the Wayne Kerr (3260B and 3261A).

Background

Transformers can be grouped into two broad classes - Power and Signal (High Frequency) Transformers. Linear power transformers generally operate at a single line frequency, and high drive levels, SMPS (switch mode power supplies) require transformers to work under similar conditions at higher frequencies. Signal transformers are required to operate from low to high drive levels and multiple frequencies; they have been traditionally used to transmit signals at audio frequencies. However in recent years the requirement has been changing to transmit high-speed digital data. Typical technologies today include ISDN, HDSL and most recently ADSL.

The basic test conditions for both groups are different. Power transformers require to be tested at fixed frequencies, with high drive levels. HF and Signal devices tend to be tested at low power and across a wide frequency range. In general they are small, often SMD parts.

Basic Measurements

Power transformers have a good correlation between the measured elements and the desired parameter, as seen in the table below, enabling a transformer to be characterised from the measured primary elements.

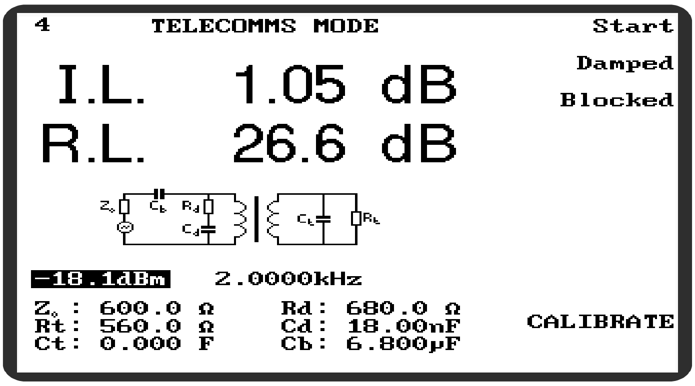
Parameters	**Elements**
Output Voltage	Turns Ratio
Magnetising Current	Primary Inductance
No Load Watts	Primary Shunt Loss (Q)
Power Loss	Winding Resistance
Regulation	Winding Resistance, Leakage Inductance

Signal transformers require a different set of measured parameters. To directly measure parameters such as insertion loss (IL) and return loss (RL) requires different terminating networks and the use of precision components, this allows high frequency measurements to be performed accurately. It is also possible to derive the required measurements such as IL and RL from accurate measurements of the primary elements shown in the table below.

Parameters	**Elements**
Return Loss	Turns Ratio squared Winding Resistance Primary L & Q Self Capacitance, Leakage L
Insertion Loss	Turns Ratio Winding Resistance Primary L & Q Self Capacitance, Leakage L

The derivation method used in the Wayne Kerr 3260B provides an advantage over the direct measurement method used in the Wayne Kerr 3261A, by allowing Insertion Loss (IL) and Return Loss (RL) to be derived without the need to connect different terminating networks and use of precision components. Using the Wayne Kerr 3260B terminating values can be entered from the instrument keypad. However above 20kHz the accuracy of the derived measurements decreases rapidly. The direct measurement technique used in the 3261A maintains accuracy for frequencies up to 3MHz. The technique also allows Longitudinal Balance (LB) and THD to be measured accurately and without the need to use different fixtures.

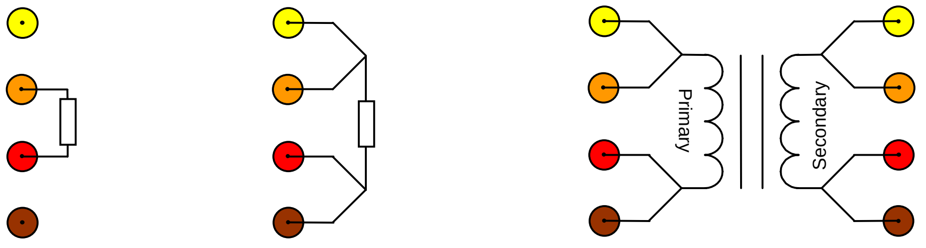
The picture below shows the 3260B Precision Magnetics Analyzer deriving IL and RL using the derivation method described above.



Basic Measurement Connections

There are a number of connection methods suited to different measured parameters. These common methods include 2-wire, 4-wire Kelvin, and Kelvin transformer. The 2-wire connection is the most basic and generally used for non-critical measurements, it is not suitable for low impedance measurements. The 4-wire Kelvin is the most common measurement connection and was originally devised for making accurate low impedance measurements. The connection to the component under test is independent of the resistance of the connecting leads. ie. cable length is unimportant. The Kelvin transformer allows simultaneous connection to the primary and secondary of a transformer. For accurate turns-ratio, you need Kelvin connections on the primary to eliminate loading effects, the secondary side only requires 2 wires, however Wayne

Kerr added two more to the secondary to allow accurate secondary Rdc and Leakage L measurement without having to change the leads.



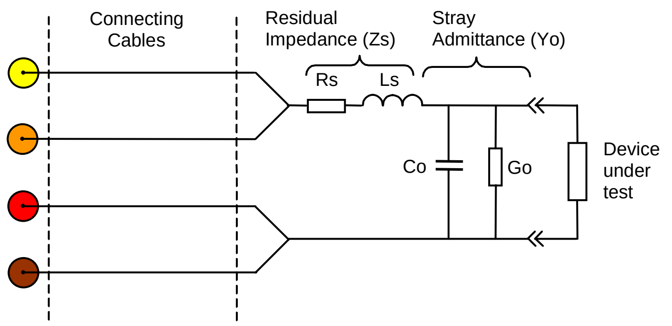
2-wire 4-wire Kelvin Kelvin transformer

<u>Symbol</u>

Brown	Sense Low
Red	Drive Low
Orange	Drive High
Yellow	Sense High

Low Frequency (LF) sources of error and applied corrections

At low frequencies there are two major sources of error. The first is due to coupling and noise between connecting leads and the second is caused by residual L, C, & R in cables and fixtures. Both are easy to correct. Noise and coupling between connecting leads can be reduced by using screened cables and residual L, C & R of the fixture and cables can be corrected by applying an offset correction through an open circuit (OC) and short circuit (SC) trim. See figure below.



Fixture Residual

High Frequency (HF) sources of error and applied corrections

At high frequencies we need to apply a different set of rules in order to compensate for measurement errors. At 50MHz everything must be terminated. For frequencies between 200kHz and approximately 5MHz the LF technique can be adapted, without the need to terminate the voltage and current sensing cables.

Errors due to unterminated cables are Scalar ie. the same at all levels and impedance's. Magnitude errors are worse than phase errors and are proportional to the frequency and cable length squared. Therefore a good basic rule is to reduce the test lead length as the frequency increases.

Example

AC voltmeter with Cin 50pF, 1m long screened input lead. At 1MHz this reads high by 0.1%. At 5MHz it becomes 2.5%.

Double the cable length and the error goes to 0.3% and 7.5% respectively.

HF Impedance measurement (V:I)

In the Impedance measurement we sense both voltage and current. However due to the unterminated voltage and current sensing cables there are errors on both these. Voltage and current sensing errors can be the same or opposite polarity depending on the configuration of the instrument but they never cancel. A correction is always needed.

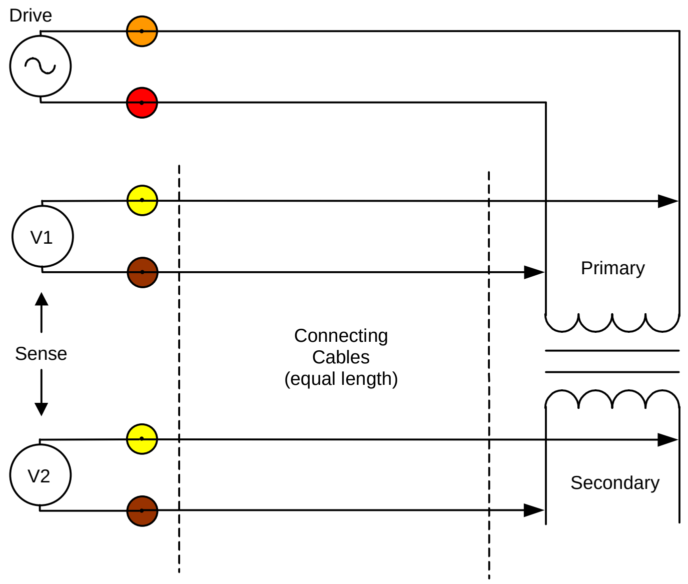
Corrections

Some equipment manufacturers use a fixed correction. But, these only remain valid if you use their test leads. Others make it user selectable dependent on cable length. However, the fixture adds errors that are dependent on the cable length, making this method inexact, the total uncertainty of the measurement being the sum of the errors in the Instrument, Cable and Fixture. Wayne Kerr use a calibration component with a known frequency response. This method works with any test lead or fixture and it allows the instrument accuracy to be maintained to the test device. The instrument runs a software routine to calculate the gain and phase errors at each frequency. This means the routine only needs to be re-run if the fixture or test leads are changed. It also allows the use of custom leads and fixtures.

The calibration component needs to have a good frequency characteristic. Suitable components include a Polystyrene or Porcelain capacitor with a value between 100 and 150pF.

HF Turns Ratio measurement (V: V)

Making a standard connection to a component for turns ratio measurement gives an additional unquantifiable error, due to the primary and secondary sense cables being of different lengths. This particular error is simply overcome by using a Kelvin connection on the primary as in the example below. The Kelvin connection to the primary gives similar sense arrangements for both the primary and secondary and the error cancels out.



HF Turns Ratio Connections

Summary

This paper has looked at the typical sources of error for both LF and HF measurements when testing transformers and identified appropriate corrections. These are summarized in the table below.

Error	**Correction**
LF Error Sources (up to 200kHz)	
Noise	Screened Cables
Cable and Fixture due to residual L, C & R	Offsets corrected by open circuit and short circuit trim
HF Error Sources (200kHz – approx. 5MHz)	
Impedance (V:I) Scalar error due to unterminated cables	Use calibration component
Turns Ratio (V:V) Scalar error due to unterminated cables	Use Kelvin connection on primary winding

The Wayne Kerr 3260B can use any measurement lead or fixture and maintain accuracy at the transformer at high frequencies. The Wayne Kerr 3260B can also derive IL and RL of line matching transformers to 20kHz. When used with the 3261A IL, RL and LB can be measured accurately to 3MHz. In addition the 3261A is able to derive THD of the transformer.

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