

VOLTECHNOTES

# Measuring Leakage Inductance



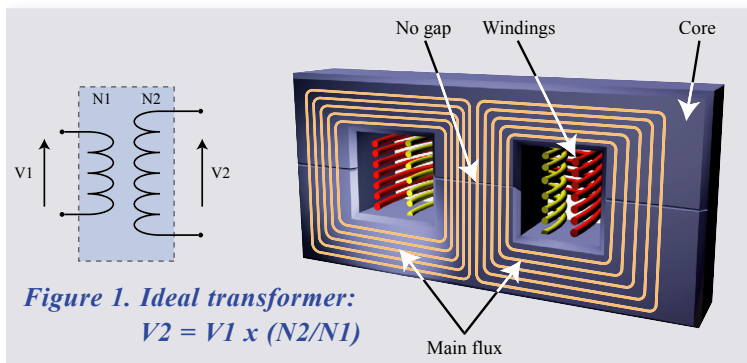
## WHAT IS LEAKAGE INDUCTANCE?

Leakage inductance is an inductive component present in a transformer that results from the imperfect magnetic linking of one winding to another. Any magnetic flux that does not link the primary winding to the secondary winding acts as inductive impedance in series with the primary, therefore this “leakage inductance” is shown on a schematic diagram as an additional inductance before the primary of an ideal transformer.

In certain applications, such as switched-mode power supplies and lighting ballasts, leakage inductance of the transformer may play a critical function in the product design. For this reason, accurate measurement of leakage inductance is often an important test function for transformer manufacturers. In order to avoid confusion with other transformer characteristics, this technical note will not refer to other components of loss such as winding resistance or inter-winding capacitance.

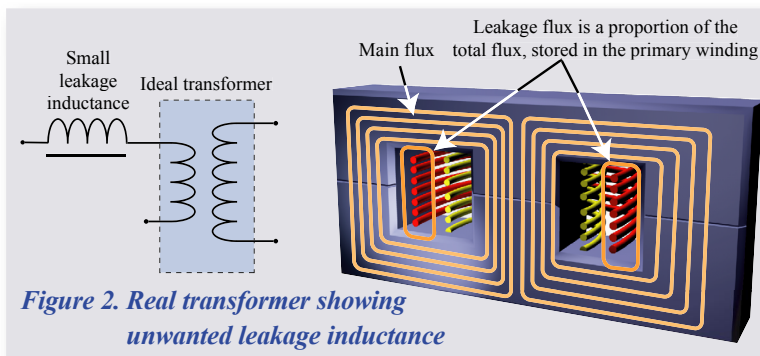
### Ideal transformer

For a theoretical, ideal transformer, there are no losses. Voltages are transformed in the direct ratio of the turns; currents in the inverse ratio of turns (figure 1).



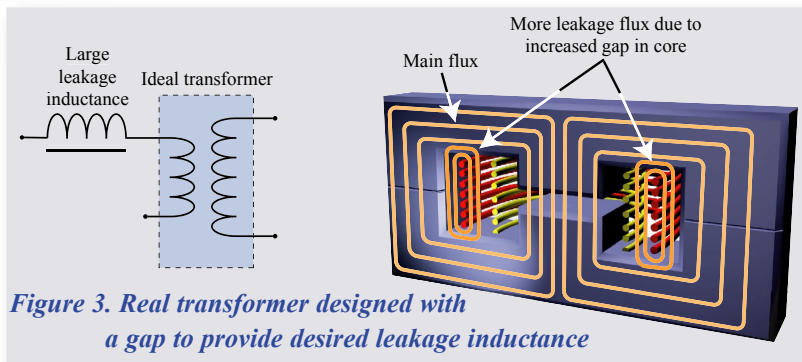
### Real transformer

In a real transformer, some of the flux in the primary may not link the secondary winding. This “leakage” flux takes no part in the transformer action and can be represented as an additional inductive impedance that is in series with the primary winding (figure 2).



## Real transformer plus an air gap

In certain transformer designs, leakage inductance must be a greater proportion of the total inductance and is specified within a tight tolerance. The increased proportion of leakage inductance is usually achieved by introducing an air gap in the core design, thus reducing the permeability of the core and therefore the value of primary inductance. The ratio of flux that does not link the primary winding to the secondary winding will therefore increase relative to the flux that links both windings (figure 3).



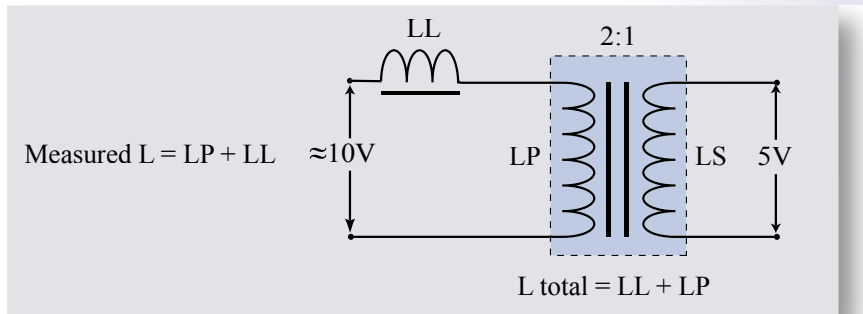
*Figure 3. Real transformer designed with a gap to provide desired leakage inductance*

## Why is measurement of leakage inductance important?

Leakage inductance (LL) may be undesirable in a wound component, in which case it is important to measure the value to show that it is low or, in some applications, such as electronic lighting ballasts and resonant power converters, leakage inductance is deliberately introduced and its value is an integral part of the circuit design. In these applications, the leakage inductance provides an energy storage medium that is essential to achieve correct operation of the finished product. It is therefore important that the value of leakage inductance of the transformer is known to be within specified limits.

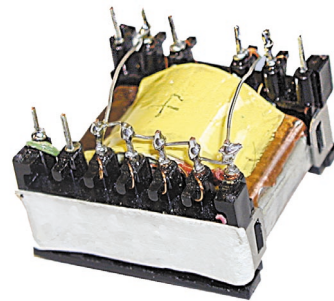
## How is leakage inductance measured?

When an LCR meter is connected to the primary winding of a transformer with open-circuit secondary terminals (figure 4), the value of inductance ( $L$ ) comprises primary inductance ( $LP$ ) plus leakage inductance ( $LL$ ).

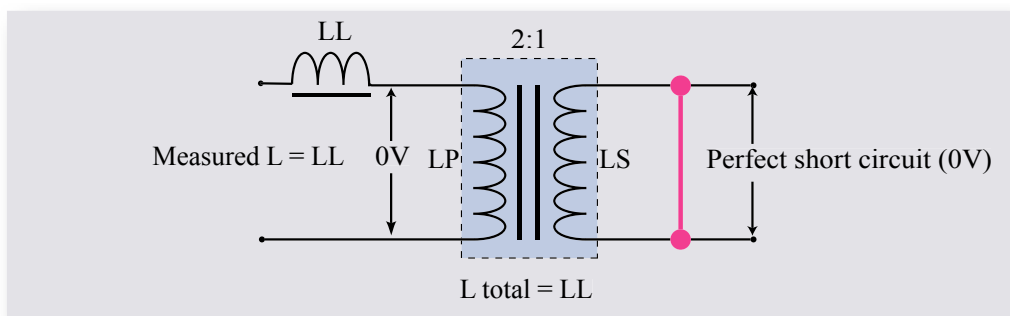


*Figure 4. Transformer with open circuit on both primary and secondary*

Since  $LL$  is a function within the transformer, it is clearly not possible to measure its value directly. A method must therefore be used to subtract the value of  $LP$  from the total measured inductance. This is achieved by applying a short circuit across the secondary terminals (figure 5). A perfect short circuit will result in zero volts on the output terminals (figure 6) and, through transformer action, zero volts will also appear across the primary inductance. The measured value of inductance at the primary terminals will therefore be the true leakage inductance ( $LL$ ).

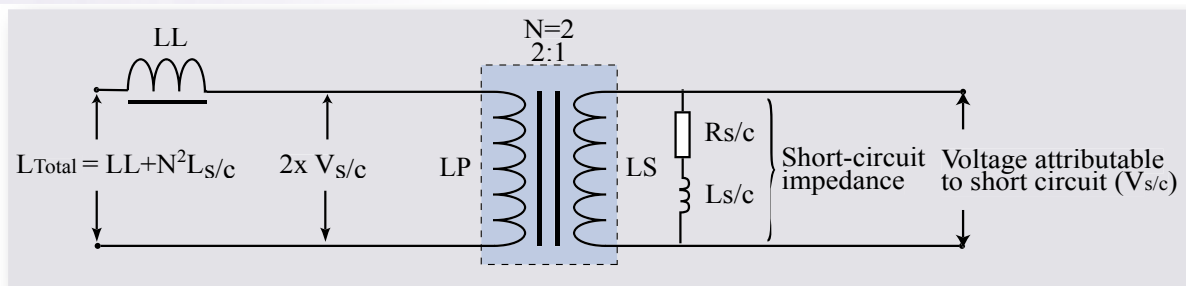


*Figure 5. Transformer with soldered short circuit(s)*



*Figure 6. Transformer with perfect short circuit across secondary*

Unfortunately, achieving a perfect short circuit on the secondary of a transformer is difficult in a laboratory and completely impractical in a production environment. In production, it is common for the short circuit to be applied manually or via a switchable relay. Under these conditions, a perfect short circuit cannot be achieved, and it follows that the secondary voltage will not be truly zero. The voltage attributable to the imperfect short circuit will then appear across the primary inductance as a short-circuit error multiplied by the turns ratio (figure 7).

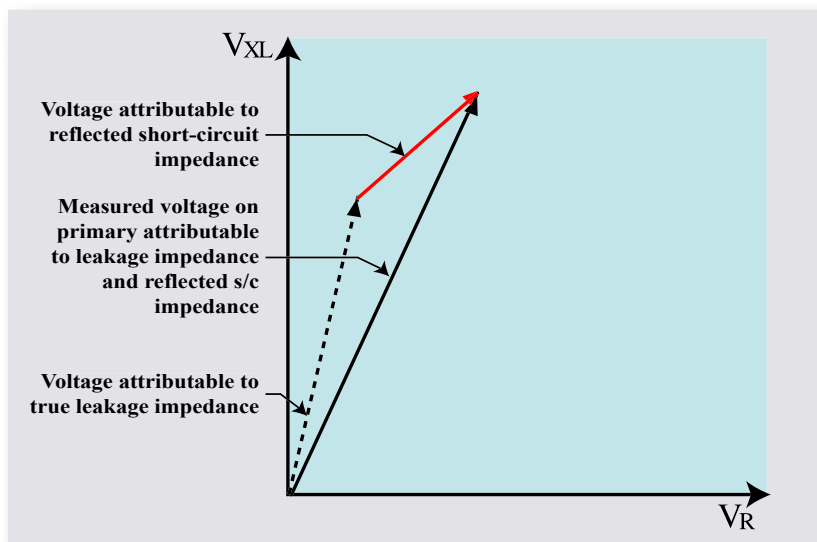


**Figure 7. Transformer with short-circuit impedance error**  
 Note: turns ratio = 2

$L_{s/c}$  is reflected in the primary as  $N^2 L_{s/c}$  because, in any winding,  $L$  is proportional to the number of turns squared ( $L \propto N^2$ ). Thus,  $L_{s/c}$  is reflected as a function of:

$$\left(\frac{N_p}{N_s}\right)^2 = \frac{L_p}{L_s}$$

The measured value of the primary inductance can be considered vectorially as the sum of the leakage impedance plus the reflected impedance of the short-circuit error. This is shown in figure 8.



**Figure 8. Vector diagram showing leakage inductance and short-circuit error**

## The traditional solution

In order to obtain the true value of leakage inductance, engineers will carefully apply a soldered short circuit to the secondary of the transformer to be tested and measure the value of inductance on the primary. This value of inductance will be recorded as the 'true' leakage inductance (e.g. 150 $\mu$ H). The inductance will then be measured on the same transformer after the soldered short circuit has been replaced by either a shorting clip or a fixture with relay-operated short circuit, depending on the technique that will be chosen for production. The measured inductance is again recorded (e.g. 180 $\mu$ H). This value will, of course, be greater than the original because it includes the true leakage inductance plus the short-circuit error inductance. The difference between these two values (in our example 30 $\mu$ H) is then used in production testing as a fixed offset that is programmed into a production LCR meter to obtain an approximation of the correct value in the presence of an imperfect short circuit.

In practice, it is impossible to achieve a relay-based or manual-based short circuit that produces exactly the same short-circuit error every time. This non-repeatability of short-circuit error is such that the fixed offset cannot provide a production department with accurate and repeatable results. This is illustrated in the following table:

	True LL	Measured value	Fixed offset	Result	Pass/fail
Measurement #1	150 $\mu$ H	180 $\mu$ H	-30 $\mu$ H	150 $\mu$ H	✓
Measurement #2	150 $\mu$ H	200 $\mu$ H	-30 $\mu$ H	170 $\mu$ H	✗
Measurement #3	150 $\mu$ H	205 $\mu$ H	-30 $\mu$ H	175 $\mu$ H	✗

## The Voltech solution

Voltech have developed their AT series testers with an architecture and processing ability to remove the short-circuit error from the primary inductance measurement during each and every test. This technique is shown vectorially below using the measured values from the preceding table as an example.

From the primary vector diagram, it can be seen that each measurement is the sum of the voltage attributable to the leakage inductance plus the error voltage from the secondary short circuit. Before applying a short circuit, the Voltech AT series testers measure the primary to secondary turns ratio. The testers then automatically apply a short circuit, using an internal relay matrix, and measure the short-circuit voltage at the transformer secondary pins. The vector of this short circuit voltage is auto-

matically multiplied by the turns ratio, producing an 'error vector' that is equal to the short-circuit error voltage reflected into the primary measurement. The leakage inductance is then computed from the total primary inductance value less the primary error vector that has been calculated. This process enables Voltech AT series testers to provide the true leakage inductance value, irrespective of short-circuit variability.

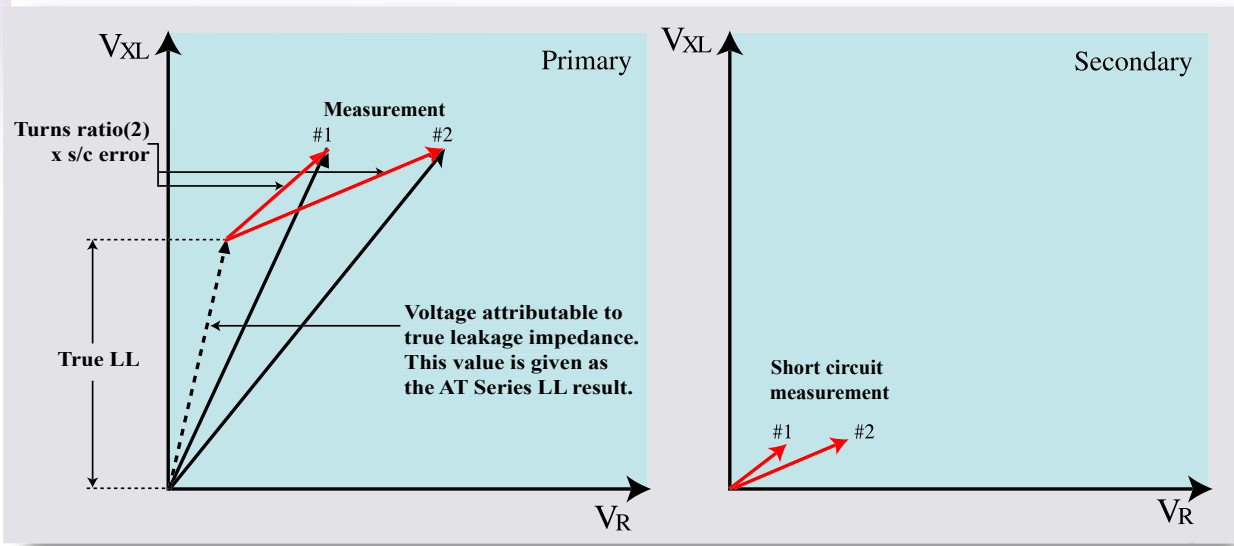


Figure 9. Vector diagrams showing measured short-circuit impedance on the secondary winding

	True LL	Measured value	Real-time vector compensation	Result	Pass/fail
Measurement #1	150μH	180μH	✓	150μH	✓
Measurement #2	150μH	200μH	✓	150μH	✓
Measurement #3	150μH	205μH	✓	150μH	✓

### Conclusion

Leakage inductance is a critical transformer characteristic that presents a particular measurement challenge to both design and production test engineers. By looking at the factors effecting measurement integrity and developing innovative measurement techniques to overcome these factors, Voltech provides a unique solution to a problem of measurement variability that faces almost all transformer manufacturers.

Should you have questions on any of the other test functions available for the Voltech AT series transformer testers, please do not hesitate to contact us.

## **VOLTECHNOTES**

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