Updating Circuit Theory

The Current Monitor Transformer

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1 Introduction

Bench testing can be used to confirm that any electronic system meets its EMC requirements, and this can be done during the development stage. One essential unit of equipment needed for this is the Current Monitor Transformer. The construction of a low-cost current transformer, its function, purpose, calibration and characterisation are described.

2 Design

Figure 1 illustrates the method of coupling the test equipment to the loop-under-test. With such a configuration, the load reflected into the primary circuit (the loop-under-test) is the load presented to the secondary divided by the square of the number of turns. Hence, the greater the number of turns, the less the value of the reflected load, and the less will be the effect of the test equipment on the system-under-review.

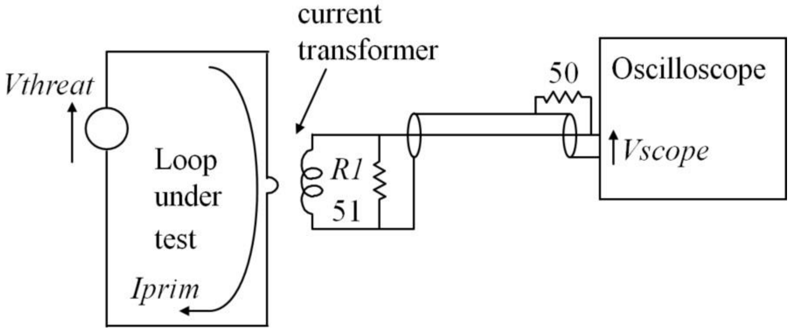


Figure 1 Use of current transformer

The load 'seen' by the secondary winding is the 51 ohm resistor *R1* in parallel with the 50 ohm impedance of the load at the input terminals of the oscilloscope. Figure 2 illustrates the relationship.

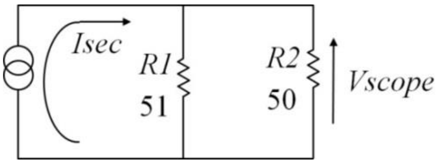


Figure 2 Transformer as a current source

The circuit model relevant to the input circuitry of the oscillope is illustrated by Figure 3. Comparing the circuit models of Figures 2 and 3 with the wiring diagram of Figure 1 shows that, as far as this configuration is concerned, the co-axial cable is transparent.

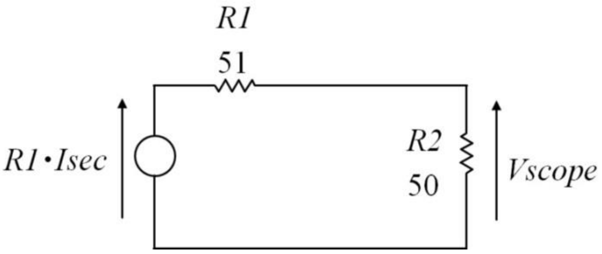


Figure 3 Transformer as a voltage source

From Figure 2, the voltage appearing at the input terminals of the oscilloscope is:

$$Vscope = Rsec \cdot Isec \tag{1}$$

Where

$$Rsec = \frac{R1 \cdot R2}{R1 + R2} \tag{2}$$

The current in the loop-under-test is:

$$Iprim = Turns \cdot Isec \tag{3}$$

where *Turns* is the number of turns on the secondary winding. From (1) and (3)

$$Vscope = R\sec \cdot \frac{Iprim}{Turns} \tag{4}$$

This means that the voltage monitored by the oscilloscope is directly proportional to the current in the loop under test. The load *Rprim* reflected into the loop-under-test is:

$$Rprim = \frac{Rsec}{Turns^2} \tag{5}$$

A current transformer meeting these design considerations was assembled using parts available from electronic components suppliers.

The core is a ‘cable suppression core assembly’ manufactured by the Fair Rite Products Corporation. The secondary winding comprises ten turns of 22 SWG enamelled copper wire. Figure 4 illustrates the assembly. The tie wrap is removable, and is used to ensure that the two halves of the core are tightly clamped together.

To characterise this transformer, a simple coupling jig was assembled. This delivered a primary current of known amplitude and known frequency, and was designed to ensure that the loop-under-test was tightly coupled to the transformer.

The test set-up is shown in Figure 5. Channel 1 of the oscilloscope was used to measure the current delivered to the transformer; that is, the current in the 50 ohm resistor placed at the scope input connector. Channel 2 was used to monitor the output of the transformer assembly.

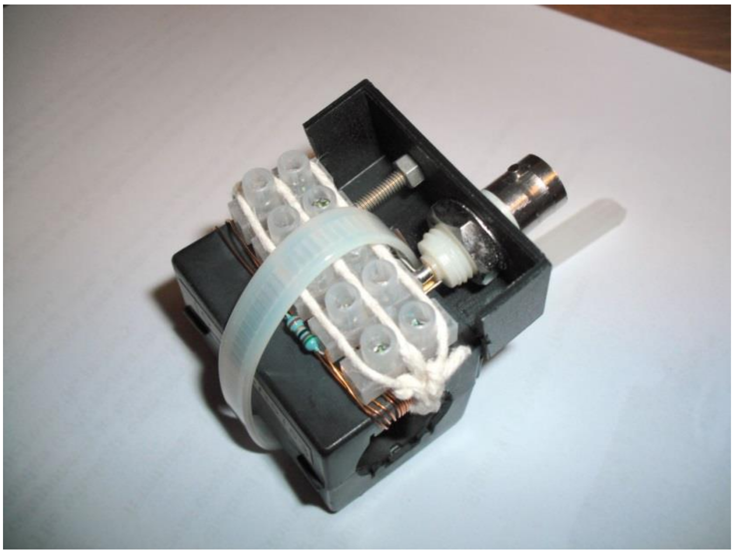


Figure 4 Current transformer assembly

The signal generator was used to deliver a constant voltage at a set of spot frequencies f_s. The peak-to-peak voltage *Vch1* at channel 1 of the oscilloscope gave a measure of the peak-to-peak current *Iprim* flowing in the primary of the transformer.

$$Iprim = \frac{Vch1}{50} \tag{6}$$

The output voltage of the transformer *Vch2* was monitored at channel 2, and the transfer impedance *ZTt* calculated. This was repeated at each spot frequency.

$$ZTt = \frac{Vch2}{Iprim} \tag{7}$$

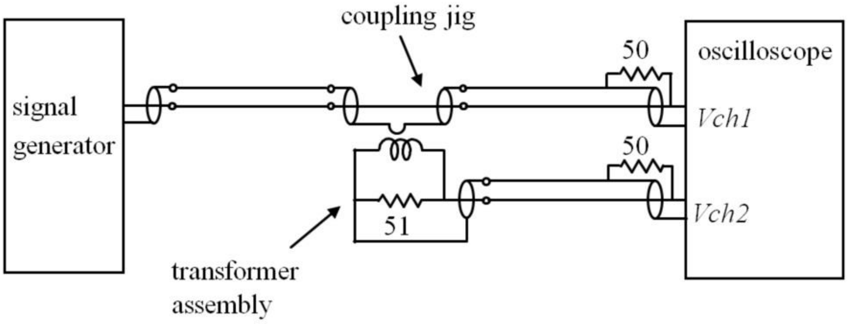


Figure 5 Setup for calibration of current transformer

A Mathcad worksheet was used to calculate and display the relationship between the transfer impedance and the frequency. The resulting graph is shown in Figure 6.

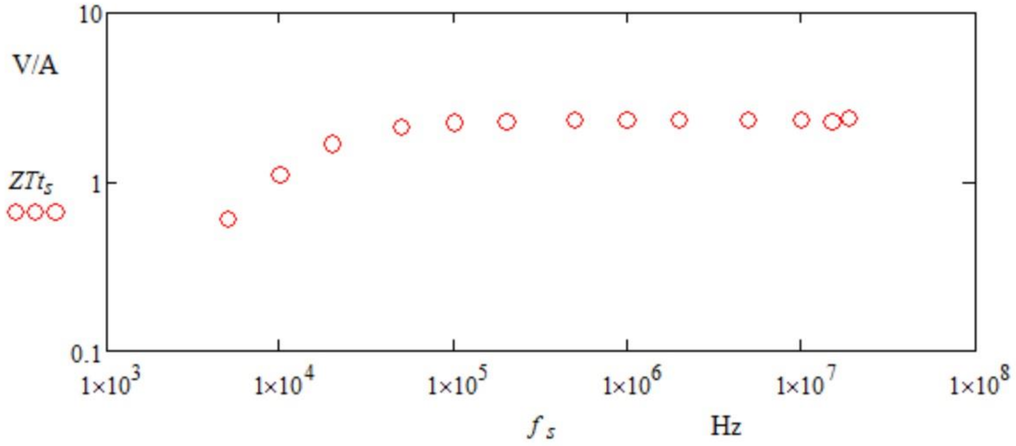
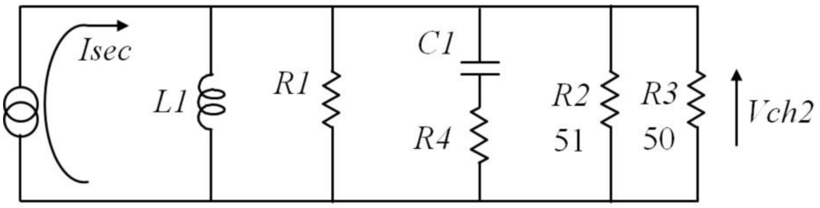


Figure 6 Transfer impedance of current transformer

The task then was to create a circuit model which replicated this relationship. .

Figure 7 is a development of the simple model of Figure 2. *R2* and *R3* represent the 51 ohm resistor in the transformer assembly and the 50 ohm resistor at channel 2 input connector respectively. *L1* represents the inductance of the transformer winding, whilst *R1* represents transformer losses. These losses could be due to the magnetic field from the loop-under-test which does not link with the transformer core. Another cause of losses is the eddy current in the core. Capacitance *C1* and resistor *R4* were added to the model to simulate additional losses at frequencies over 2 MHz.



$$Iprim = Isec \cdot Turns$$

Figure 7 Circuit model of current transformer

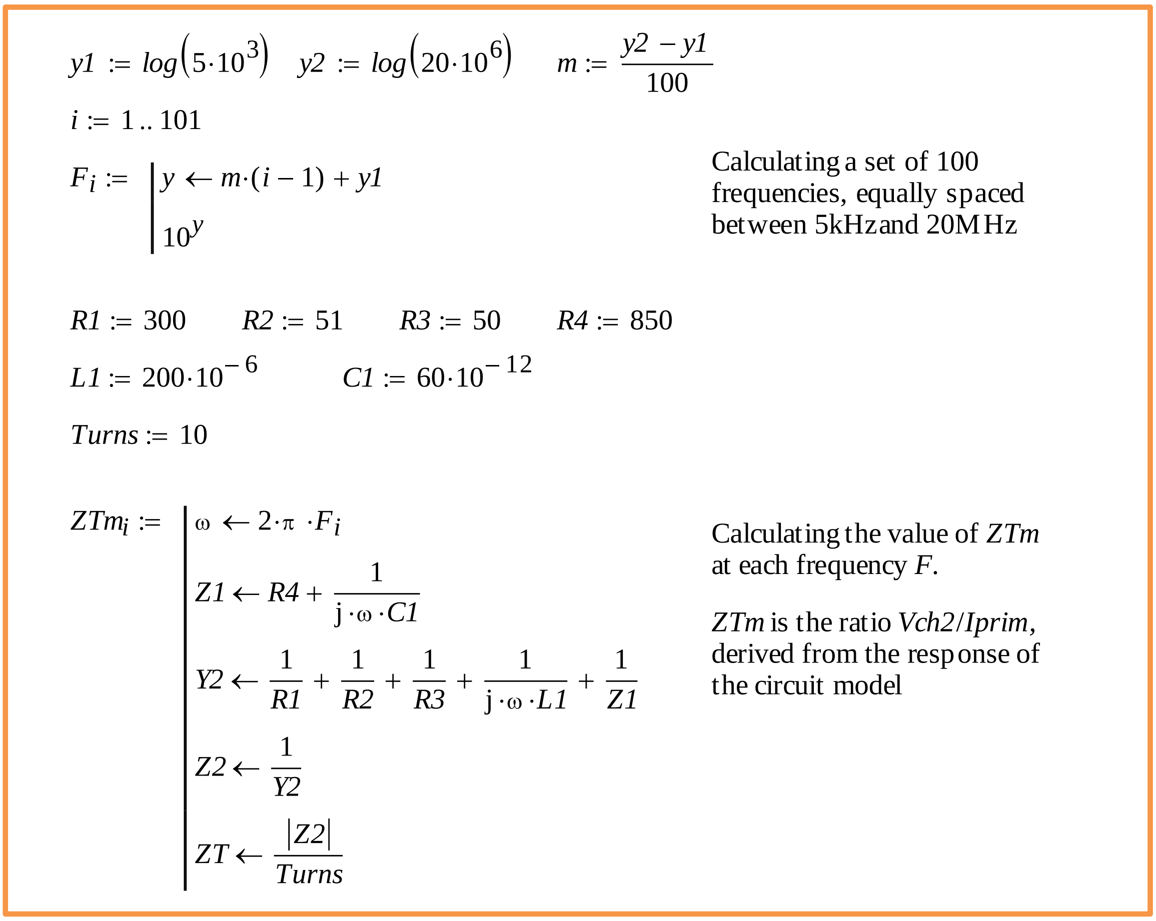
A copy of the Mathcad worksheet used to carry out a frequency response analysis of this circuit model is provided by Figure 8.

This worksheet first calculates a set of 100 frequencies, on a logarithmic scale between 5 KHz and 20 MHz and stores them in the vector ***F***. It then defines the component values of the circuit model as well as the number of turns *Turns* on the secondary.

The equations used in the function *ZTm* are derived from an inspection of the circuit model. The impedance *Z2* is the impedance as ‘seen’ by the current generator. It defines the ratio of

*Vch*2 to *Isec*. Dividing *Z2* by the number of turns gives the ratio of *Vch*2 to *Iprim*. That is, the transfer impedance of the circuit model.

Figure 9 illustrates the correlation between the test results and the response of the model. Although there was an initial discrepancy between the two curves, a few adjustments of *L1* and *R1* led to a curve which intersected the data points at the low frequencies. Varying the values of *C1* and *R4* led to a curve which intersected the data point above 2 MHz as well. The process is akin to the use of successive approximations to solve non-linear equations.



$$y1 := \log\left(5\cdot 10^{3}\right) \qquad y2 := \log\left(20\cdot 10^{6}\right) \qquad m := \frac{y2 - y1}{100}$$

$$i := 1 .. 101$$

$$F_i := \left| \begin{array}{l} y \leftarrow m\cdot(i-1) + y1 \\ 10^{y} \end{array} \right.$$

Calculating a set of 100 frequencies, equally spaced between 5kHz and 20MHz

$$R1 := 300 \qquad R2 := 51 \qquad R3 := 50 \qquad R4 := 850$$

$$L1 := 200\cdot 10^{-6} \qquad C1 := 60\cdot 10^{-12}$$

$$Turns := 10$$

$$ZTm_i := \left| \begin{array}{l} \omega \leftarrow 2\cdot\pi\cdot F_i \\ Z1 \leftarrow R4 + \dfrac{1}{j\cdot\omega\cdot C1} \\ Y2 \leftarrow \dfrac{1}{R1} + \dfrac{1}{R2} + \dfrac{1}{R3} + \dfrac{1}{j\cdot\omega\cdot L1} + \dfrac{1}{Z1} \\ Z2 \leftarrow \dfrac{1}{Y2} \\ ZT \leftarrow \dfrac{|Z2|}{Turns} \end{array} \right.$$

Calculating the value of *ZTm* at each frequency *F*.

ZTm is the ratio *Vch2*/*Iprim*, derived from the response of the circuit model

Figure 8 Calculating the transfer impedance of the circuit model

The end result is a model which effectively defines the relationship between the current in the loop under test and the voltage measured at the input terminals of the oscilloscope. That is, measurements of *Vch2* can be used to calculate the value of *Iprim* at any frequency in the range 5kHz to 20MHz.

This being so, Figure 10 can be described as a ‘Definitive Circuit Model’ for this particular transformer.

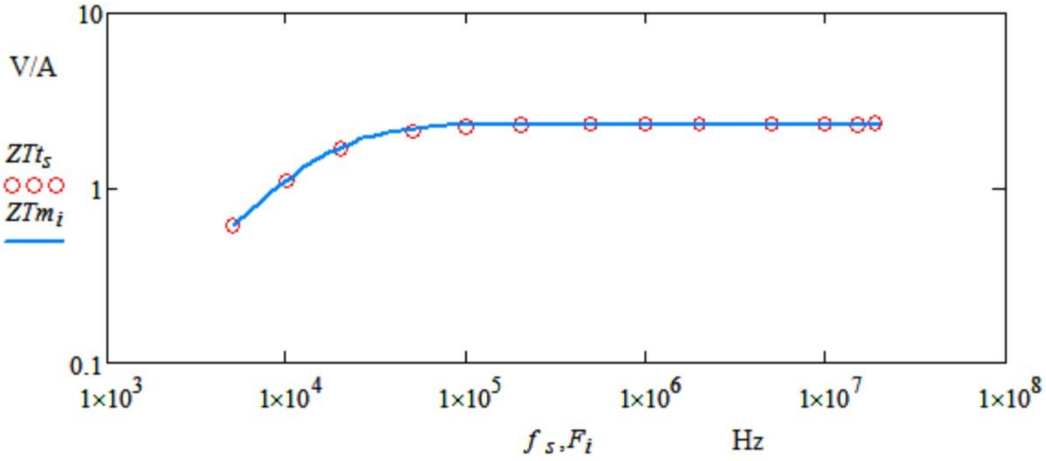
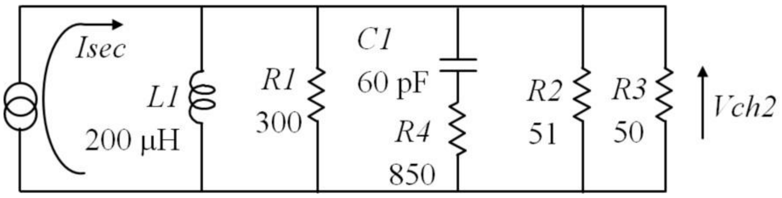


Figure 9 Correlating the circuit model with the test results



$$Iprim = Isec \cdot Turns$$

Figure 10 Definitive circuit model

3 Conclusion

This article describes the construction of a low-cost current transformer, its function, purpose, calibration and characterisation. It can be used to measure amplitude of any current in any cable routed through the core. In this particular example, the bandwidth is from 10 kHz to 20 MHz. Since the reflected impedance in the assembly under test is extremely low, it has minimal effect on the characteristics of that assembly.

The transformer has been used to carry out a wide variety of cable coupling experiments. It is well suited to the task of bench testing of cable assemblies and or in-situ testing of system installations, prior to formal EMC testing.

The technique can be used to develop low-cost current transformers which operate over lower frequency ranges or higher frequency ranges.