Updating Circuit Theory – Transfer Admittance

Ian Darney

Introduction

The previous article described a model which simulated the frequency response of the emission of a twin-conductor cable. This article shows that this response is identical to the susceptibility characteristic.

In any analysis of EMI, the most critical parameter is the Transfer Admittance – the ratio of the current delivered to the victim loop to the voltage applied to the culprit loop.

In the case of the configuration under review, the culprit loop is that carrying the differential-mode signal and the victim loop is that between the cable and the virtual conductor simulating the environment. Here, the Transfer Admittance defines the emission characteristic.

If the voltage source was in the antenna-mode loop, then the Transfer Admittance would be the ratio of the current induced in the differential-mode loop to the amplitude of that voltage source. This is a measure of the susceptibility of the configuration.

It is shown that the Transfer Admittance is the same, whether the measurement is of radiation susceptibility or radiated emission. This is also true for conducted susceptibility and conducted emission.

Although Transfer Admittance is an essential parameter in any analysis of EMC, it cannot be measured by any formal EMC test. The only engineers with the freedom to carry out such analyses are those who design the equipment under test.

Analysis

The loop equations for the circuit shown in Figure 1 are:

$$V_1 = (Z1 + Z2) \cdot I_1 - Z2 \cdot I_2 \tag{1}$$

$$0 = -Z2 \cdot I_1 + (Z2 + Z3) \cdot I_2 \tag{2}$$

Re-arranging (2)

$$I_1 = \frac{Z2 + Z3}{Z2} \cdot I_2 \tag{3}$$

Substituting for I_1 in (1)

$$V_1 = \frac{(Z1 + Z2) \cdot (Z2 + Z3)}{Z2} \cdot I_2 - Z2 \cdot I_2 \tag{4}$$

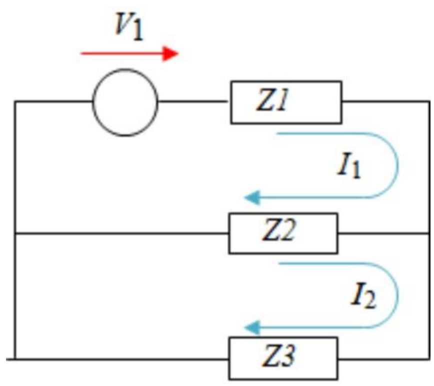


Figure 1 Calculating Transfer Admittance

this expands to $$V_1 = \frac{Z1 \cdot Z2 + Z1 \cdot Z3 + Z2 \cdot Z2 + Z2 \cdot Z3 - Z2 \cdot Z2}{Z2} \cdot I_2 \quad (5)$$

giving $$\frac{I_2}{V_1} = \frac{Z2}{Z1 \cdot Z2 + Z1 \cdot Z3 + Z2 \cdot Z3} \quad (6)$$

If the voltage source is located in the second loop, as shown in Figure 2, then the same process leads to

$$\frac{I_1}{V_2} = \frac{Z2}{Z1 \cdot Z2 + Z1 \cdot Z3 + Z2 \cdot Z3} \quad (7)$$

This means that the Transfer Admittance *YT* is the same, whether the voltage source is located in loop 1 or loop 2.

$$YT = \frac{I_1}{V_2} = \frac{I_2}{V_1} \quad (8)$$

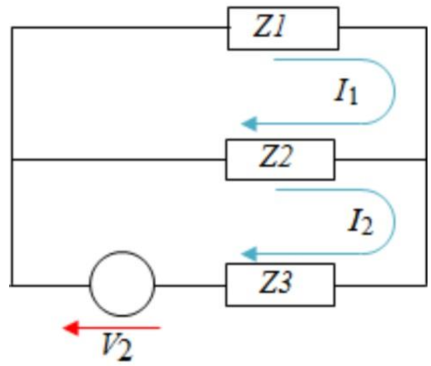


Figure 2 Voltage source in Loop 2

Since the coupling between the culprit and victim loops can be simulated by a circuit model of the configuration under review and since the transfer admittance is the same if the roles are interchanged, it follows that the response to a measurement of the emission characteristic can be used to define the susceptibility.

Principle of Reciprocity

Reviewing equations (6) and (7) reveals the fact that the numerator on the right hand side is the only impedance common to both circuit loops and that the denominator is the sum of the products of every pair of impedances in the two loops. This property will apply to every pair of loops which share a common impedance.

For a network with many loops, this interrelation continues to be valid. It follows that the ratio of the current in loop *i* to the voltage in loop *j* is identical to the ratio of the current in loop *j* to a voltage source in loop *i*.

$$\frac{I_i}{V_j} = \frac{I_j}{V_i} \tag{9}$$

Radiated Emission and Radiation Susceptibility

Figure 3 is a copy of the circuit model used to measure the Radiated Emission characteristic of an isolated length of twin-conductor cable. The red curve on Figure 4 shows the frequency response of the conducted emission when a voltage source *Vsignal* is applied and the voltage source *Vthreat* is zero.

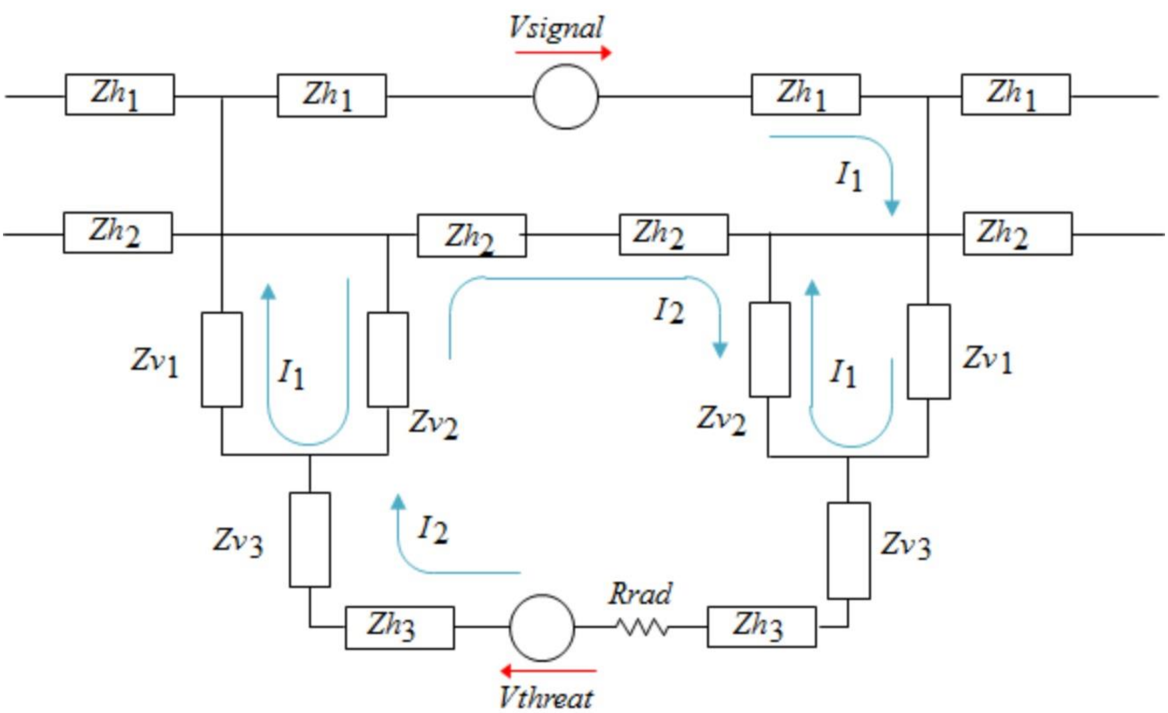


Figure 3 Circuit model used to simulate radiated emission characteristic of twin-core cable

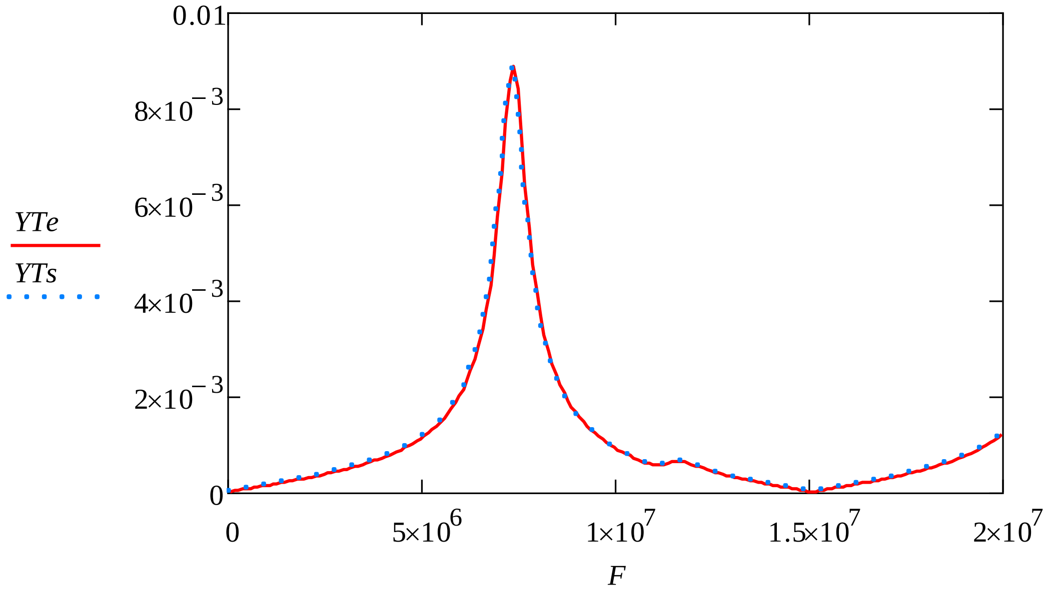
In figure 3 the radiated emission is defined as:

$$YTe = \frac{I_2}{Vsignal} \tag{10}$$

and the radiation susceptibility is defined as:

$$YTs = \frac{I_1}{Vthreat} \tag{11}$$

The fact that the red curve *YTe* simulates the actual response of the hardware is demonstrated by the article ‘Updating Circuit Theory - Cable Characterisation’. The fact that the blue dots of *YTs* lie precisely on the red curve demonstrate that the analysis of the simple model of Figures 1 and 2 applies to the more complex model of Figure 3.



red curve - Transfer admittance of radiated emission -*YTe*
blue dots – Transfer admittance of radiation susceptibility- *YTs*

Figure 4 Response of circuit model of cable characterisation test

The curve of *YTe* versus frequency can be described as the Radiated Emission characteristic of the cable-under-test. The curve of *YTs* can be described as the Radiation Susceptibility of that same cable – the differential- mode current induced in the cable by a voltage of 1 Volt created by an external electromagnetic field.

That is, a test of the Radiated Emission can be used to predict the Radiation Susceptibility of the configuration under review

Conducted Emission and Conducted Susceptibility

Figure 5 is the circuit model developed to simulate the cross-coupling between the differential-mode signal and the induced current in the common-mode loop. Details of the actual test and the creation of this model are described in the article 'Updating Circuit Theory – The Signal Link'

The red curve of Figure 6 is a copy of the Transfer Admittance *YTe* of that particular setup – the curve relating the current I_2 induced in the common-mode loop by a voltage *Vsignal* in the differential-mode loop. In the parlance of EMC requirements, this can be described as a Conducted Emission test.

The blue dotted curve *YTs* of Figure 6 is the ratio of the current I_1 induced in the differential-mode loop by a voltage *Vthreat* in the common-mode loop. That is, the predicted response of a test of the Conducted Susceptibility of the Signal Link.

This means that a test of Conducted Emission can be used to predict the results of a Conducted Susceptibility of any configuration under review – and vice versa.

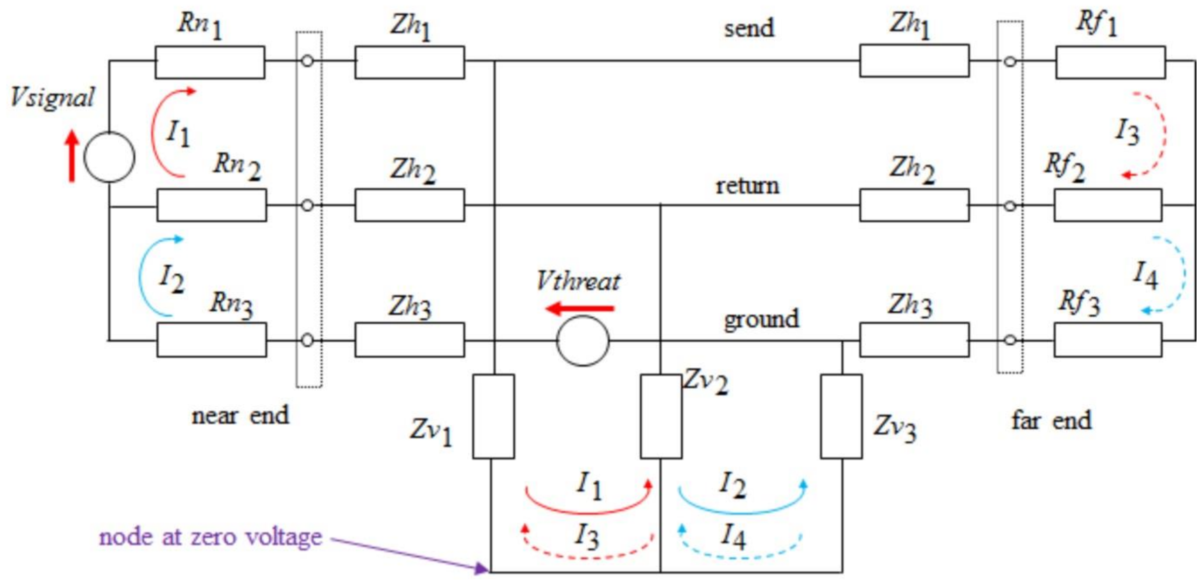
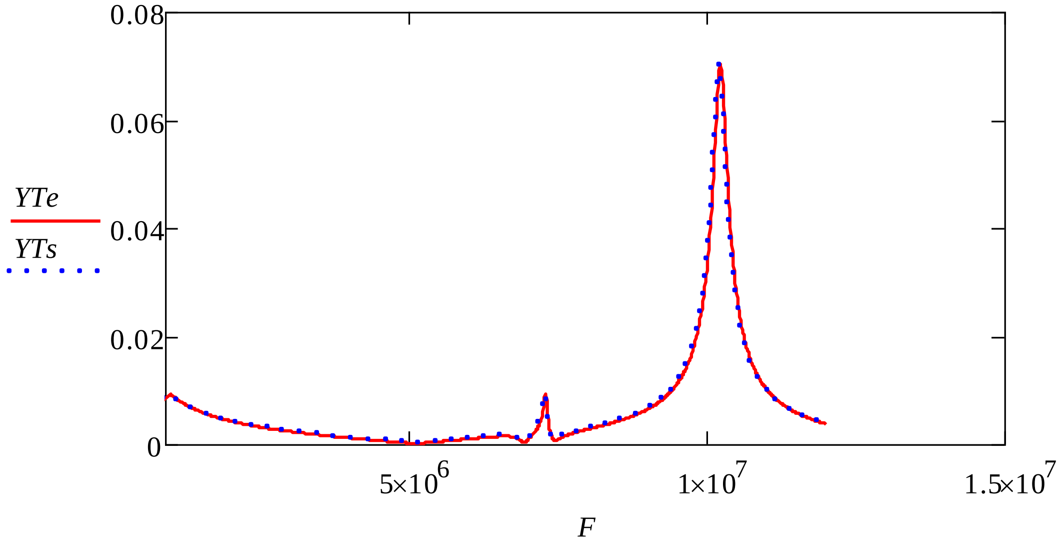


Figure 5 Circuit model of Signal Link



red curve - transfer admittance of conducted emission

blue dots – Transfer admittance of conducted susceptibility

Figure 6 Response of circuit model of signal link.

Conclusion

It has been shown that the Transfer Admittance is an essential parameter in any analysis of the coupling of electromagnetic interference to and from the equipment under test (EUT). Even so, it has no place in any of the multitude of formal EMC requirements.

The reason for this is the demarcation in the way these requirements are written. Of necessity, there is no need for the engineers at the Test House to know the internal workings of the EUT. The test equipment and the use of that equipment are the sole responsibility of technicians at the test facility. The EUT and its functional behaviour are the sole responsibility of the equipment designer.

For susceptibility requirements, a severe electromagnetic environment is created by the EMC test equipment. Then the EUT is tested to check that it still functions properly. It some cases, the functional behaviour of the EUT is monitored by the equipment designer during the testing to confirm that no abnormal behaviour was detected.

For emission requirements, the EUT is cycled through a set of functions, designed to create maximum electromagnetic interference and the test equipment is monitored to ensure that none of the specified test limits is exceeded.

The problem with this demarcation is the need for the regulatory requirements to be framed in such a way that all eventualities are covered. This means that the formal documents are replete with legalistic jargon and require significant expertise in interpreting their precise meaning. Working groups update the regulations at regular intervals.

So there are three groups of engineers: those who formulate the EMC requirements, those who carry out the tests, and those who design the EUT.

Equipment designers soon came to the conclusion that EMC requirements are so complex that there is no point in trying to understand the phenomena. This led naturally to the creation of a fourth group; EMC experts who offer their expertise in the form of multiple and varied guidelines as to how to design equipment to meet those requirements. But the experts who offer this advice are long gone when the manufactured equipment is submitted to the EMC Test House.