# Circuit Modelling for Electromagnetic Compatibility

## Concepts

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This is one of a set of articles available for download from the website www.designemc.info . Comments will be welcome.

### 1 Introduction

Electromagnetic compatibility (EMC) is as amenable to the design process as any other design requirement. Key to the approach is the use of circuit models to simulate and analyse all the interference coupling mechanisms. Such an approach provides the equipment designer with a clear understanding of those mechanisms and the ability design the system-under-review to meet the EMC requirements in a systematic and cost-effective way.

This article introduces the underlying concepts.

### 2 Simplifying assumptions

The mechanisms involved in the coupling of interference are governed by the laws of physics and these particular laws are defined by the formulae of Electromagnetic Theory. These laws also control the functional behaviour of electronic systems, behaviour which is analysed by the much simpler mathematics of Circuit Theory.

Given these facts, it is reasonable to describe Circuit Theory as a development and simplification of Electromagnetic Theory. However, the simplifications inherent in the present-day usage of Circuit Theory which make it capable of analysing the behaviour of extremely complex electronic systems also render it ineffective in any analysis of interference coupling. The keyword in the previous sentence is ‘usage’. If the simplifying assumptions can be identified and modified, then Circuit Theory can also be used to analyse interference.

The most significant of these assumptions is the concept of the ‘equipotential ground’ which manifests itself in the use of the ubiquitous ‘earth’ or ‘ground’ symbols found scattered around present-day circuit diagrams. It is assumed that every point identified by such a symbol is held firmly at zero voltage. SPICE has become totally dependent on this concept.

Other assumptions are, that a conducting link between two nodes of a circuit diagram has zero impedance, that action and reaction are simultaneous at all locations in the system, and that there is no interaction between the circuit and the environment. These apparent obstacles to the use of circuit modelling can be overcome.

**3 The signal link**

If it is recognised that every conductor in a system possesses the properties of inductance capacitance and resistance, then it follows that transient current in any conductor will create a voltage along that conductor. A voltage will exist between any two points designated as being at ground potential. The effect of this can be minimised by assigning a 'return' conductor to return the current delivered by the 'send' conductor back to the voltage source. There will be two paths between sender and receiver for the return current; the return conductor and the structure, as illustrated by Figure 1. Coupling between the signal loop and the ground loop is inevitable, no matter how the terminations are configured.

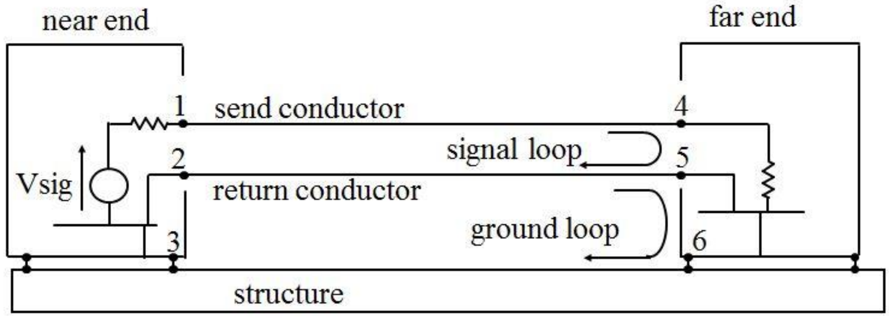


Figure 1 Basic signal link

A circuit model which simulates the coupling of interference between these two loops is illustrated by Figure 2. Each conductor is represented by a T-network of inductors, resistors and a single capacitor. The task of assigning numerical values to the L, C, and R components of the model is dealt with in the article on Lumped Parameters [1].

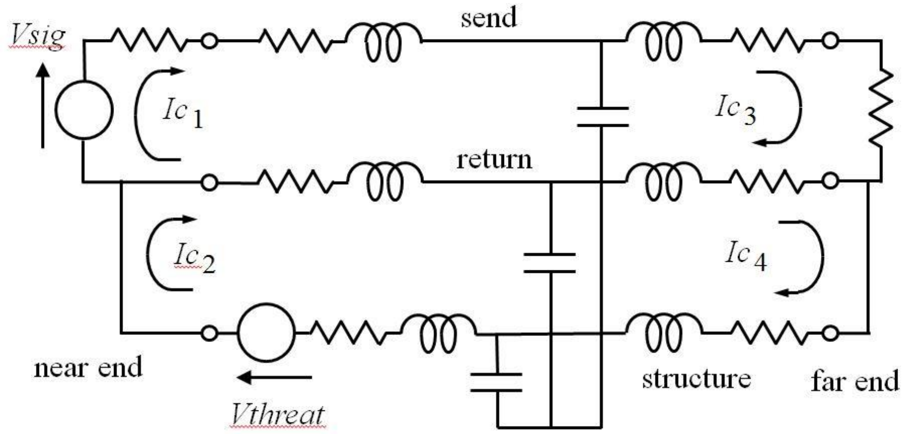


Figure 2 Circuit model of signal link

If the only path available for the return current between the two units of equipment is the structure, or the 'earth' conductors of the power supplies, then there is no point in trying to analyse EMC.

**4 The circuit diagram as a model.**

Before the advent of the desk computer, one method of predicting the behaviour of the servo system of a rocket launcher was to relate the currents and voltages generated by an analogue computer to the mechanical properties of the system-under-review.

A simple illustration of this relationship is provided by Figure 3. An assembly of a simple damping system is shown by Figure 3a. If an extra mass is dropped on the weight, then the system will oscillate. The equation of motion is essentially the same as that of the LCR circuit of Figure 3b, where the parameters of force, displacement, velocity, mass, and damping factor are replaced by voltage, charge, current, inductance, and resistance.

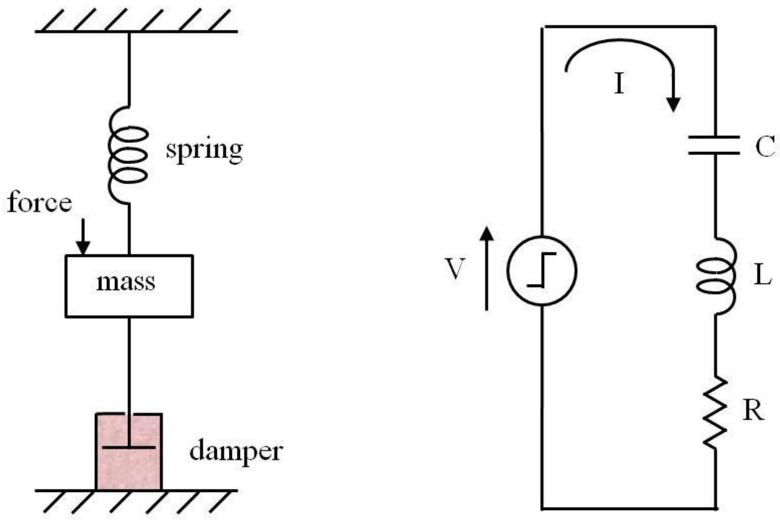


Figure 3a. Damping system    Figure 3b. Circuit model

Figure 3 Use of circuit model to simulate a mechanical system

The circuit model can be regarded as a pictorial representation of a set of equations. In concept, this is the same as treating it as the unknown variable in mathematical problems.

**5 Developing the model**

A basic limitation inherent in normal usage of Circuit Theory is that action and reaction are instantaneous throughout the system. This is not so. The velocity of propagation of current and voltage is finite. Transmission line theory caters for this by deriving a pair of hybrid equations which relate current and voltage at the sending end to current and voltage at the receiving end of the line. This derivation can be developed further to define a pair of loop equations which can be manipulated using the rules of Circuit Theory.

The lumped-parameter model of Figure 2 can be replaced by the distributed-parameter model of Figure 4. These two figures are so named because the first assumes that inductance capacitance and resistance are discrete components, whilst the second caters for the fact that these three parameters are distributed along the length of the cable. The transformation formulae are identified in the article on Transmission Lines and Antennas [2].

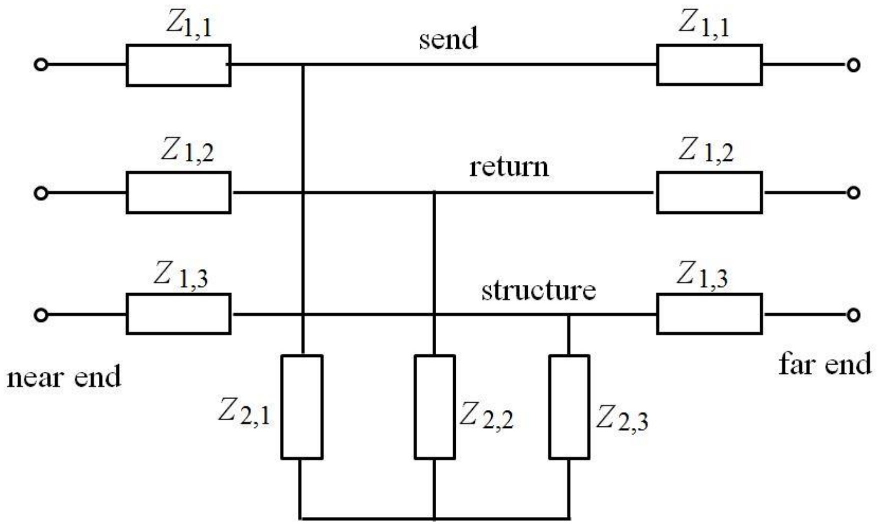


Figure 4. Distributed parameter model of signal link conductors

**6 The radiation resistor**

The theory of the dipole antenna identifies the concept of the Radiation Resistance. It is not a component in the sense that it can be purchased from a supplier. It is a mathematical constant derived from the analysis of the power density of the electromagnetic field over a spherical surface enclosing a transmitting antenna. When a dipole is providing maximum radiated power output, the load presented to the transmitter is purely resistive. This leads to the resistance *Rrad* in the model of Figure 5.

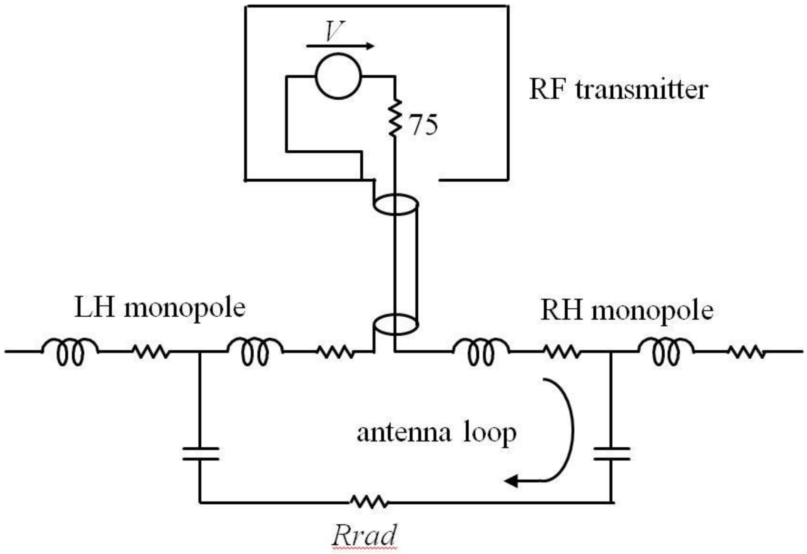


Figure 5. Lumped-parameter model of dipole antenna.

The reactive components act as a series tuned circuit. At resonance the only components limiting the current delivered to the environment are the resistors. Although the model is defined in terms of lumped parameters, it is analysed in terms of distributed parameters.

## 7 The virtual conductor.

Since the model of Figure 5 represents each monopole as a T-network, it is a simple step in the reasoning to speculate that if a twin-conductor cable were to replace one of the monopoles, with the structure acting as the other, the result would be the model illustrated by Figure 6.

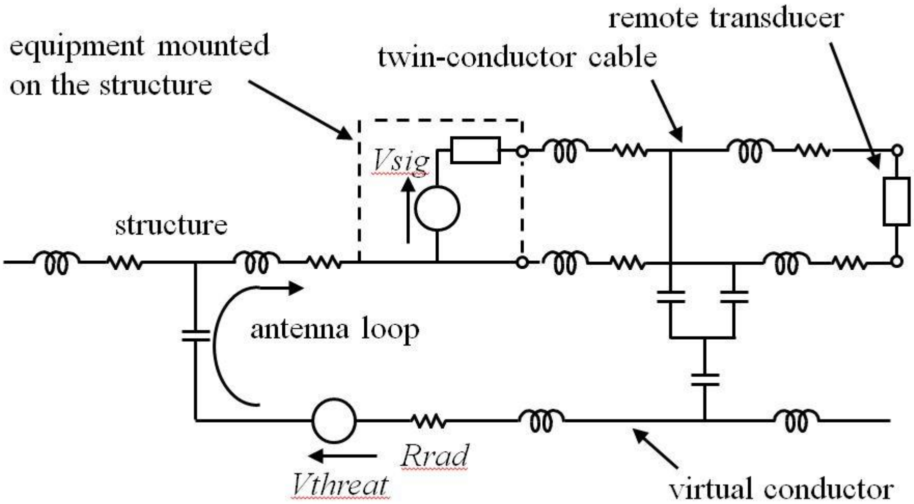


Figure 6 General circuit model of exposed cable and structure

Since the assembly of components representing the environment of each monopole is configured as a T-network and since every conductor of the signal link is also configured as a T-network, it is natural to identify this assembly as a Virtual Conductor [2]. Again, the lumped parameters are changed into distributed parameters during the analysis.

## 8 Radiated interference

For susceptibility analysis, the threat voltage *Vthreat* can be calculated by relating it to the electric field of the threat environment.

To analyse emission, it is assumed that the threat voltage is zero. A voltage source *Vsig* at the near end of the signal link will generate a current *Irad* in the antenna loop. The maximum field strength *H* at a radius *r* due to *Irad* can then be calculated.

The formulae relating *Vthreat* and *Irad* to the intensity of the associated fields are defined in reference [2].

## 9 Bench testing

Having established a method of modelling any signal link, the way is open for correlation to be established between the performance of the actual hardware and the simulation provided by the model.

Figure 7 illustrates a bench test setup which can be used to measure susceptibility. The clamp-on transformer injects a common-mode voltage into the cable and channel 1 of the oscilloscope monitors this voltage. Simultaneously, channel 2 monitors the effect of this voltage on the function of EUT1.

Figure 8 illustrates a setup which can be used to measure conducted emission. In this test, the voltage delivered to the sending end of the signal link is derived from the signal generator and monitored by channel 1. Channel 2 monitors the amplitude of the common-mode current.

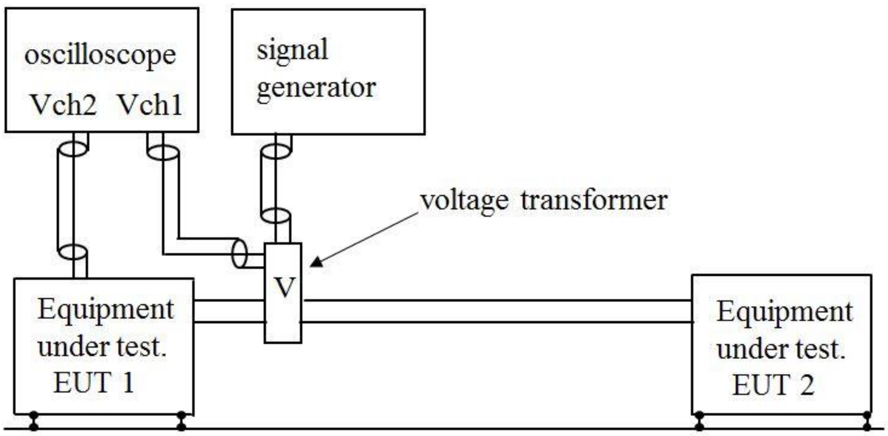


Figure 7 Bench test of conducted susceptibility

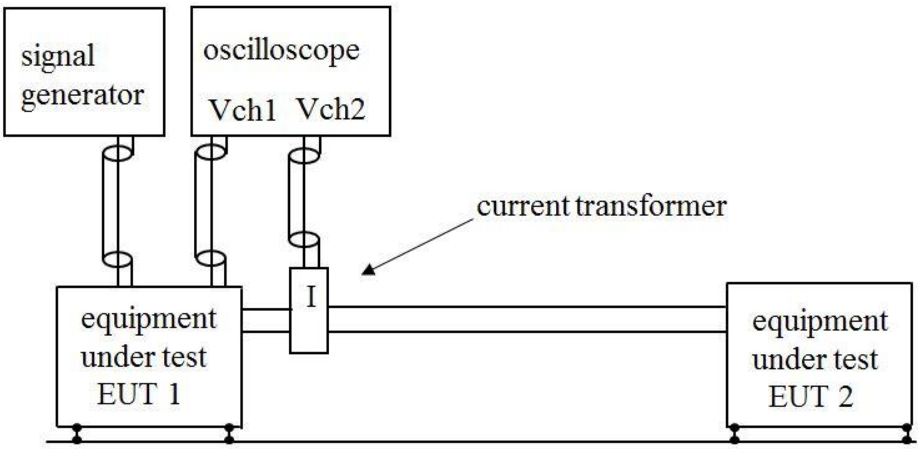


Figure 8 Bench test of conducted emission

In both tests, the designer can monitor input and output simultaneously. With formal testing, the engineers at the Test House do not have that option.

The article on Bench Testing provides more information on this approach [3].

The ability to carry out bench tests and create a circuit model of the interference coupling parameters means that is becomes possible to predict the outcome of formal EMC testing and implement corrective measures before submitting the manufactured equipment to the Test House.

## 10 Conclusion

**I**t is possible to create circuit models which can be used to analyse all forms of interference coupling; conducted emission, conducted susceptibility, radiated emission, and radiation susceptibility. This article has identified the underlying concepts.

## 11 References


[1] Lumped Parameter Models. www.designemc.info/12Lumped.pdf

[2] Transmission Lines and Antennas. www.designemc.info/13TransmissionLines.pdf

[3] Bench Testing. www.designemc.info/14BenchTesting.pdf