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# MODELING OF BUNDLE WITH RADIATED LOSSES FOR BCI TESTING

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**Abstract** – In order to simulate the BCI [1] (Bulk Cable Injection) tests we try to derive an equivalent model of the wires leading to the DUT (Device Under Test). This model will be used to perform test simulations according to automotive specifications [2].

The standard does not specify the relative position of the wires. But, in lot of cases, their positions are preponderant. The simulation is a very good way to estimate their influence.

## 1. INTRODUCTION

The automotive manufacturer and their suppliers must pay more and more attention to EMC problems. But, the cost of EMC test is very expensive when a product has a problem during validation test. The aim of this study is to create tools in order to simulate BCI test (described below) during development.

The main difficulty is to find a proper model to simulate the wires linking the different parts car applications. Moreover, you can have splices on the wires. The first idea is to use an existing model of wire (microstrip). This model has a heavy limitation: one cannot simulate easily more than 3 wires in a bundle. The second idea is to develop a lumped model.

## 2. BCI TEST

### 2.1 BCI Presentation

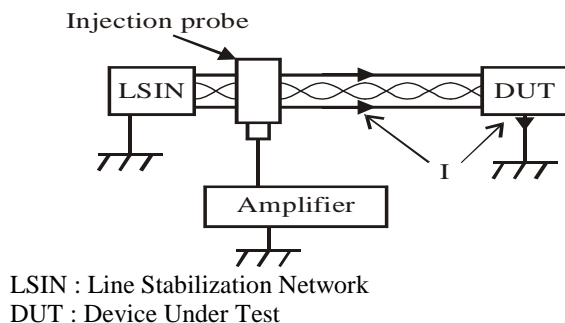


Fig 1: BCI test bench on shielded cable

The BCI test consists in injecting a current on wires. One must test all bundles leading to a DUT (Device Under Test). To inject the current one can use a magnetic injection probe. The cable is 5cm above the ground plane. The first application of this standard is on shielded cables (Fig 1); afterwards the use was generalized to all types of cables (Fig 2).

### 2.2 Problems encountered in BCI test

#### 2.2.1 On shielded cable

For the injection probe, the input impedance is close to a short circuit (Fig 1). The test is based on the transimpedance of the shielded cable. In this case, the equivalent circuit is a current transformer with a ratio close to one. This is generally a substitution test.

#### 2.2.2 Automotive application

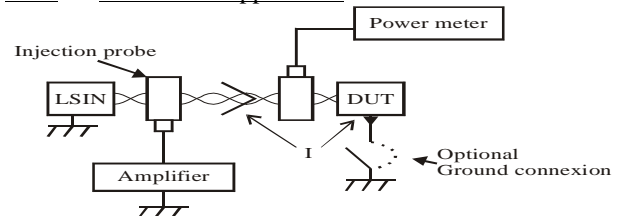


Fig 2: BCI on unshielded cable

In most of cases, the DUT is not connected to the ground. Reaching a current on a floating system (Fig 2) reveals a lot of discrepancies, particularly for low frequencies. The manufacturer specified a calibration method to define a nominal power, and a test with double limitation: current and power. We increase power until the nominal DUT current reaches the defined level. At the same time the injected power is limited to calibrated power multiplied by 4 or 8 depending on manufacturer.

The different consequences of those manipulations:

- Uncontrolled "differential mode" current within the bundle
- Great influence of relative position of cables

- Great influence of the LSIN impedance (or auxiliary equipment).

### 3. MICROSTRIP MODEL

In order to understand the DUT comportment we must simulated the BCI benchmark. One part of the simulation is the wires.

#### 3.1 Single wire

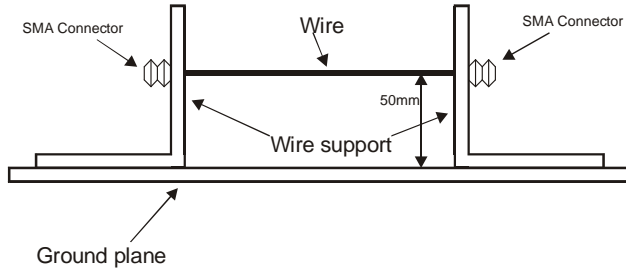


Fig 3: Single wire montage

To find the model, we realize the montage presented in Fig 3. The wire is 1m long and is connected to a network analyser. We choose a frequency spectrum from 150kHz to 150MHz. This spectrum is the widest radio input spectrum.

The measurement shows the circuit is very close to a 290 Ohms transmission line. The equivalent circuit consists in a simple microstrip model (Fig 4).

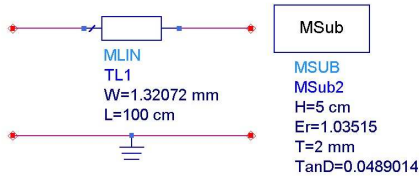


Fig 4: microstrip wire model

The identification of the S parameters of the simulated model and those measured give us the remained parameter:

- The relative dielectric constant ( $\epsilon_r=1.0089$ )
- The losses of structure derived as dielectric losses ( $tg\delta=0.049$ )

despite the fact that the losses are due to radiation.

#### 3.2 Double wire

With the preceding measurement (Fig 3), we find a very simple model (Fig 4) and we try to extend it to a couple of wires as shown in Fig 5.

A coupled microstrip model with the same parameter works perfectly.

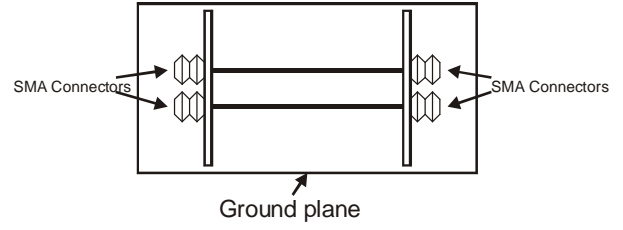


Fig 5: Two wires montage

#### 3.3 Splice

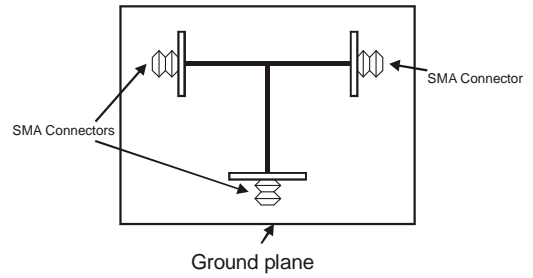


Fig 6: One wire with splice

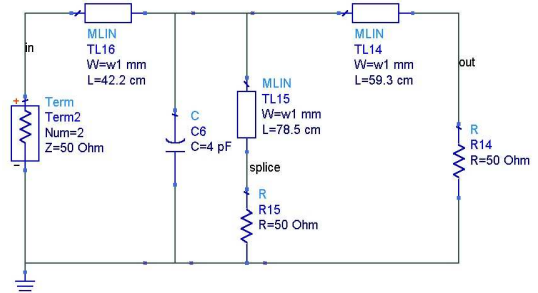


Fig 7: Equivalent circuit and measured circuit

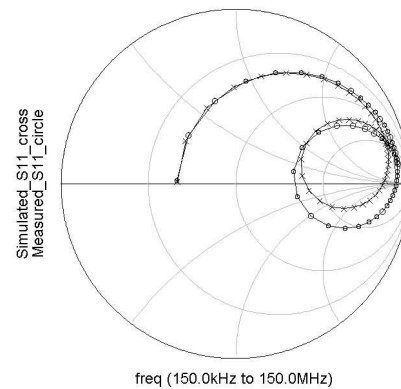


Fig 8: Result of simulated and measured circuit

In the case of splice (Fig 6), the convergence between microstrip and measurement is not good enough. But a condensator between interconnexion and ground plane on the microstrip model (Fig 7) allows a good agreement as shown on Fig 8.

### 3.4 Double wire with splice

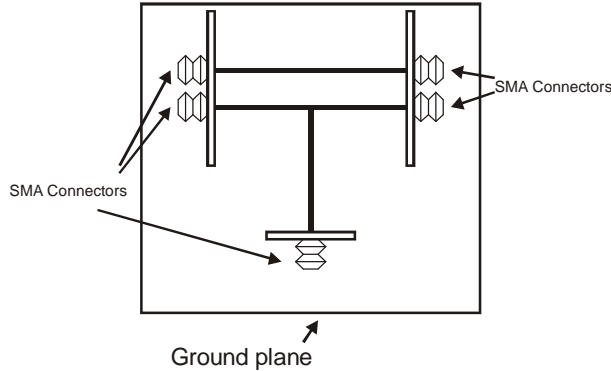


Fig 9: Two wires and splice montage

For this new configuration (Fig 9) we start with the simulation (Fig 10) and simply make verification with measurement.

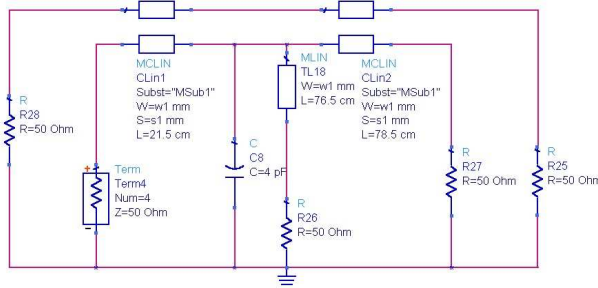


Fig 10: two wires with splice model

The simulation is very close to measurement (Fig 11). The port 1 is the measurement and port 2 is the simulation.

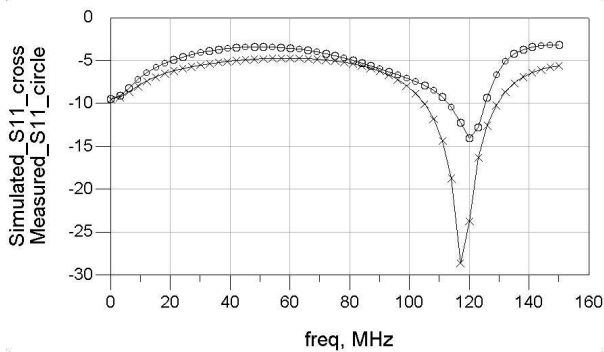


Fig 11: Two wires with splice comparison

## 4. LUMPED COMPONENTS MODEL

The main problem encountered with the microstrip models is that we cannot get more than 3 wires. So a model with lumped elements was derived in order to simulate bundle with more than three wires.

### 4.1 Single wire model

We carry out measurement on a 116cm long single wire (Fig 3).

We try to use the standard model of transmission line, but the model does not include the radiative losses. Moreover, there are few losses by conduction and no loss in the dielectric (air).

With a lumped components model (Fig 13) the radiative losses can be included in the resistors (R1 and R2). This model is for 10cm transmission line. To obtain the 116cm, 12 basic elements were cascaded.

The electric length is about one twentieth of the wavelength at the highest frequency.

When we compare in Fig 12 measurement, microstrip model and lumped components model, we find the lumped components model is the better one.

In Fig 12, ports 1-2 are the ports of measurement, 3-4 are the ports of lumped components model and, 5-6 are the ports of microstrip model.

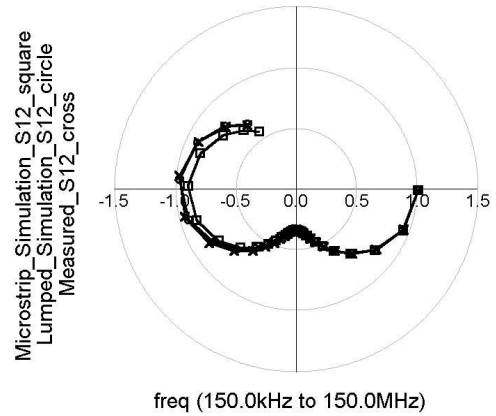


Fig 12: comparison between different models

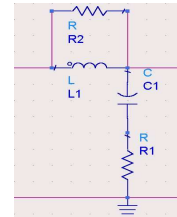


Fig 13: Lumped components model detail

Each cell (Fig 13) represents 10cm long.

$L1 = 94\text{nH}$ .  $C1 = L1/Z_t$  with  $Z_t = 290\text{ Ohms}$ .

$R2 = 30\text{kOhms}$  and  $R1 = Z_t^2/R2$ .

### 4.2 Double wires model

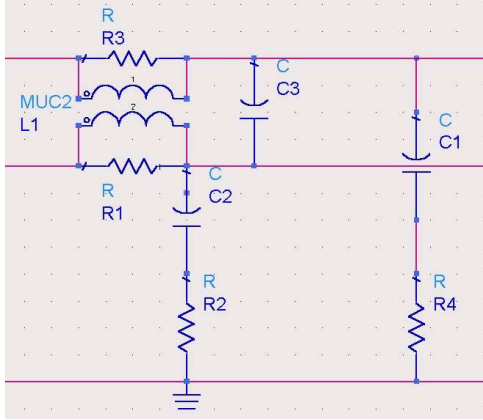


Fig 14: Double wires lumped components model detail

In this new model (Fig 14) we only change the inductance L1 (Fig 13) with an electric transformer. The coupling coefficient is 0.75 with 2 cables distant of 1mm. The coupling capacitor C3 is 2pF.

All the other components have the same values than previously.

The comparison between measurements and the model is shown on Fig 15 and Fig 16.

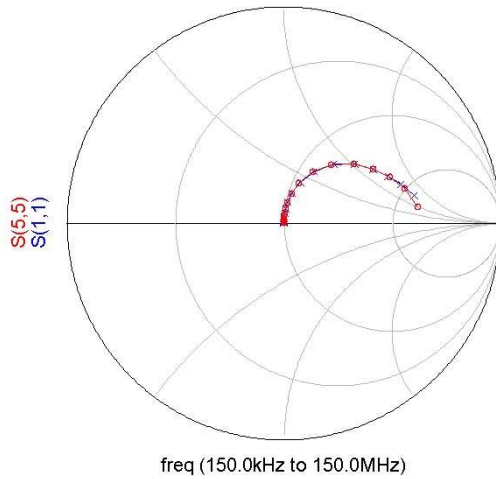


Fig 15: input S-parameters

X : Simulated result  
O : Measured result

On Fig 16, the two left curves are the direct transmission, and the four others curves are the transmission on the second wire.

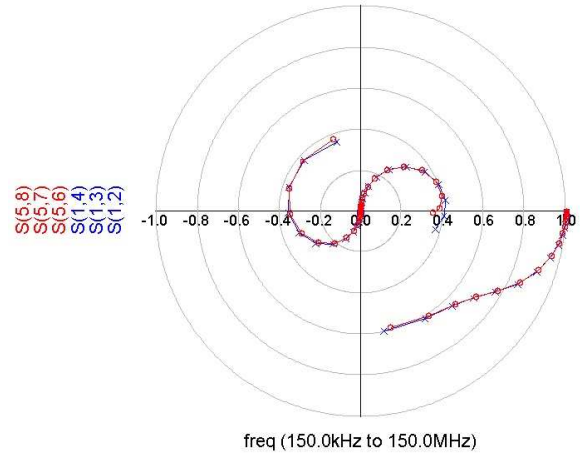


Fig 16: Transmission S-parameters

## 5. CONCLUSION AND FURTHER WORK

This work allows us to simulate easily several wires with radiative losses. The agreement between model and measurements is very good and let us think that the lumped model is ready for further simulations

We currently work on a seven-wire bundle model that can be simply added to a simulator. A three-wire model has been also derived and is very similar to the two-wire lumped components model.

## 6. REFERENCES

[1] BCI defined in MIL-STD-461D, MIL-STD-462D and new one MIL-STD-461E

[2] RENAULT spécification 36-00-808/--D

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