DOUBLE BULK CURRENT INJECTION : A NEW HARNESS SETUP TO CORRELATE IMMUNITY TEST METHODS

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Abstract : Double Bulk Current Injection (DBCI) method has been proposed to reproduce the same current injection obtained in the case of an electromagnetic coupling with an incident plane wave. Good correlation can be obtained between this DBCI method and the stripline method, and also between DBCI and anechoic chamber methods. But there is no simultaneous correlation between these three methods because the stripline and the anechoic chamber methods are not based on the same coupling modes. This paper proposes a new harness setup conserving the standard harness length of 1 metre, in order to obtain a good correlation between all three test methods. The experimental validation given in this paper shows very encouraging results.

Keywords : BCI, test method, automotive equipment, anechoic chamber, stripline, DBCI.

Introduction

In the automotive domain, the immunity of electronic devices is first studied by performing EMC tests on the equipment and its harness alone on a test bench. In a second phase, these equipment are then retested in the vehicle connected to the final harnesses. Several standards [1] define the test methods in order to evaluate the immunity levels of electronic equipment against electromagnetic interferences on test bench. The aim of these immunity tests is the acceptance or not of the electronic equipment. Although the standards define the upper frequency limit to 18 GHz, they are usually performed on a frequency band between 10 kHz to 2 GHz. Three different test methods are mainly used to cover this frequency range : the Bulk Current Injection (BCI) method, the semi-anechoic chamber method and the stripline method.

BCI is a qualification method aiming to evaluate the immunity level of electronic equipment by conduction, injecting directly a current on the harness between a simulator and the equipment under test by the use of an injection probe. In the ISO documents [1], this method is recommended to qualify the immunity of on-board equipment towards narrow band emissions in the 1 MHz - 400 MHz frequency band. The semi-anechoic chamber method is also used to evaluate the immunity levels of electronic equipment. It uses antennas as radiating devices and the equipment under test and its harness are therefore submitted to an electromagnetic field. The tests are generally performed between 10 kHz and 2 GHz according to the ISO documents. Therefore, due to the usual size of the chamber and its absorbers, the efficiency of the tests is usually obtained above 80 MHz. The stripline method also creates an electromagnetic field in which is placed only the harness connected to the equipment under test beneath the ground plane. The height of the stripline imposes the maximum frequency band which is presently between 10 kHz and 200 MHz.

Even if each of these qualification methods covers a different frequency range with large common sections, it should be preferable that the three entirely different test methods lead to the same results in their common frequency bands. Unfortunately, no satisfactory correlation has ever been obtained between these three qualification methods, mainly because of their test setup. In [2], it has been demonstrated that the BCI method does not reproduce the current distribution along a harness nor the induced currents in the loads which can be observed when the harness is submitted to a plane electromagnetic wave. As the anechoic chamber and the stripline methods are both based on a plane electromagnetic wave coupling, the correlation between the BCI method and the two others is very difficult to obtain in most cases.

Furthermore, the Double Bulk Current Injection method (DBCI) is proposed as an improvement of the standard injection method which offers the advantage of reproducing the same injected currents in the loads as those obtained in the case of several specific plane wave coupling modes.

In particular, further experiments [3] using a same test bench have demonstrated that good correlation can be obtained, on the one hand between a specific DBCI configuration and the anechoic chamber method, and on the other hand between another DBCI configuration and the stripline method. The problem actually stands in the fact that there is no simultaneous correlation between these three methods because of the difference of coupling between the anechoic chamber method and the stripline method.

The aim of this paper is to propose a new common harness setup in order to obtain a good correlation between all three previous test methods. The first part of this paper will give a brief overview of the DBCI method principle and will present the comparison between the results obtained, on the one hand with the DBCI and the anechoic chamber methods, and on the other with the DBCI and the stripline methods. Justified by a theoretical approach, the second part of this paper will propose a new harness setup and will highlight the benefits of this new setup by experimental validations.

I – Comparison between the DBCI method and the other test methods

1. Background

Let us consider the case of a lossless conductor placed at a height **h** above a ground plane that we will assume perfectly conducting (figure 1). This conductor is connected at its ends by two linear or non-linear loads Z(A) and Z(B).

If the wavelength of the incident plane wave is much greater than the height **h** separating the conductor from the ground plane, and if we neglect the electromagnetic coupling on the vertical conductors at each end, the transmission line model can be applied. The propagation equations expressing the coupling of an incident plane wave can be therefore expressed by :

$$\begin{cases} \dfrac{\partial V(z,t)}{\partial z} + L\,\dfrac{\partial I(z,t)}{\partial t} = \mathcal{E}_p(z,t) \\[2mm] \dfrac{\partial I(z,t)}{\partial z} + C\,\dfrac{\partial V(z,t)}{\partial t} = \iota_p(z,t) \end{cases} \qquad (1)$$

where V(z,t) and I(z,t) are respectively the total voltage and the total current at a position z of the transmission line at an instant t, $B^{i}_{y}(z,t)$ the transversal component of the incident magnetic field and $E^{i}_{x}(z,t)$ the vertical component of the incident electric field. The two right sources $\mathcal{E}_p(z,t)$ and $\iota_p(z,t)$ are respectively the per-unit-length elementary voltage and current sources along the transmission line :

$$\begin{cases} \mathcal{E}_p(z,t) = \dfrac{\partial}{\partial t}\displaystyle\int_o^h B^i_y(z,t)\,dx \\[2mm] \iota_p(z,t) = -\,C\,\dfrac{\partial}{\partial t}\displaystyle\int_o^h E^i_x(z,t)\,dx \end{cases} \qquad (2)$$

As the height **h** is considered to be very small versus the wavelength, the expression of these sources can be reduced to :

$$\begin{cases} \mathcal{E}_p(z,t) = h\,\dfrac{\partial B^i_y(z,t)}{\partial t} \\[2mm] \iota_p(z,t) = -\,C\,h\,\dfrac{\partial E^i_x(z,t)}{\partial t} \end{cases} \qquad (3)$$

Deriving equations (1) respectively by z and t, and applying

$$\vec{\mathrm{rot}}\ \vec{E}^i = -\frac{\partial \vec{B}^i}{\partial t} \qquad (4)$$

we obtain the following system of equations :

$$\begin{cases} \dfrac{\partial^2 V}{\partial z^2} - L\,C\,\dfrac{\partial^2 V}{\partial t^2} = L\,C\,h\,\dfrac{\partial^2 E^i_x}{\partial t^2} - h\,\dfrac{\partial^2 E^i_x}{\partial z^2} + h\,\dfrac{\partial^2 E^i_z}{\partial x\,\partial z} \\[2mm] \dfrac{\partial^2 I}{\partial z^2} - L\,C\,\dfrac{\partial^2 I}{\partial t^2} = -C\,h\,\dfrac{\partial^2 E^i_z}{\partial x\,\partial t} \end{cases} \qquad (5)$$

Introducing a virtual voltage U :

$$U = V + h\,E^i_x \qquad (6)$$

these equations become :

$$\begin{cases} \dfrac{\partial^2 U}{\partial z^2} - L\,C\,\dfrac{\partial^2 U}{\partial t^2} = h\,\dfrac{\partial^2 E^i_z}{\partial x\,\partial z} \\[2mm] \dfrac{\partial^2 I}{\partial z^2} - L\,C\,\dfrac{\partial^2 I}{\partial t^2} = -C\,h\,\dfrac{\partial^2 E^i_z}{\partial x\,\partial t} \end{cases} \qquad (7)$$

The background of the DBCI method is based on the equivalent circuit in the cases of Ez = 0. These cases are the ones encountered when the incident plane wave is coupled to the transmission line in the directions and orientations defined in figure 1.

In these cases, equations (7) become :

$$\begin{cases} \dfrac{\partial^2 U(z,t)}{\partial z^2} - L\,C\,\dfrac{\partial^2 U(z,t)}{\partial t^2} = 0 \\[2mm] \dfrac{\partial^2 I(z,t)}{\partial z^2} - L\,C\,\dfrac{\partial^2 I(z,t)}{\partial t^2} = 0 \end{cases} \qquad (8)$$

The equivalent electric circuit corresponding to the transmission line propagation equations (8) is given in figure 2. The aim of the DBCI method is to reproduce by any means the two voltage sources inserted at each end of the transmission line.

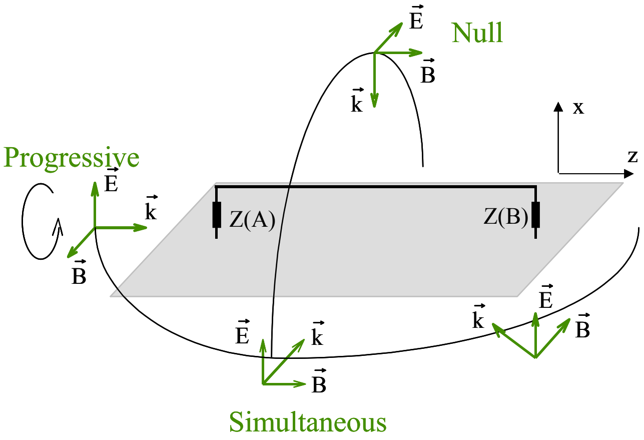

Figure 1 : Plane wave coupling in the case of $E_z = 0$

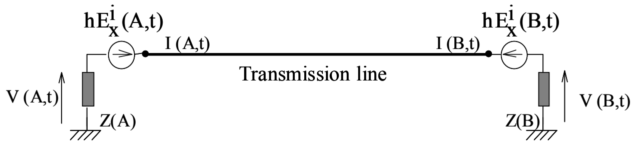

Figure 2 : Equivalent electric circuit in the case of $E_z = 0$

The DBCI test bench evaluated in [2,3] is based on the use of two injection probes inserted at each end of the harness (figure 3), and fed by two synchronized RF sources. For practical reasons, these two sources are provided by the same generator by means of a power splitter.

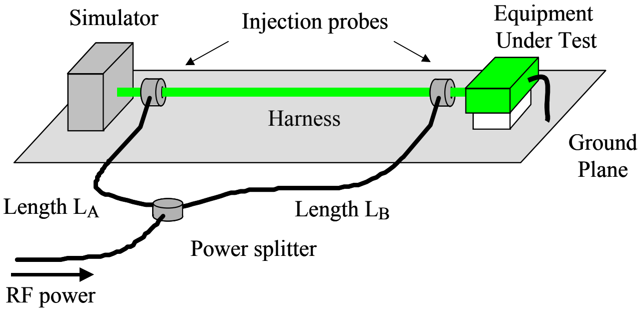

Figure 3 : A typical DBCI test bench

As defined in figures 1 and 2, the DBCI method can simulate different coupling directions by simply imposing the delay between the equivalent voltage sources applied at each end of the harness. This delay can be created by a different of length between the power splitter and each injection probe as shown in figure 3. For instance, and as defined in figure 1, simultaneous coupling can be reproduced when the lengths L_A and L_B are equal, whilst progressive coupling can be obtained when the difference of length between L_A and L_B introduces a delay equal to the propagation delay of the electromagnetic wave between each end of the harness.

In order to determine the theoretical evolution of the currents in 50Ω loads at the extremity of a 1 metre length transmission line, a numerical simulation is performed by the Method of Moments (MoM). Figure 4 gives the numerical simulation results as well as the experimental BCI result. This is a typical result highlighting the differences that can be found between the currents created by the BCI method and those obtained by an electromagnetic coupling. These curves will serve as reference to analyze further results.

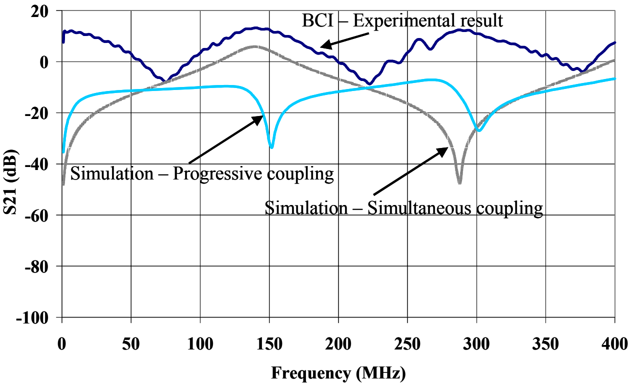

Figure 4 : Simulation results and an experimental BCI result

2. The experimental test bench

The comparison between the three standard test methods is not straightforward because the layout of the ground plane and the harness are different in the case of the stripline method. Therefore, the test bench built for the comparison of the different methods is designed in such a way that the harness under test and the loading remain unchanged whatever the method. For future industrial exploitation reasons, it is built by taking into account and putting in common the existing standard configurations. In the three cases, the test bench is placed in an anechoic chamber. The harness is replaced by a 1 metre straight conductor placed at 5 cm above a 1.25m x 0.75m ground plane and connected to 50Ω loads at each end. The height of the ground plane from the floor is 0.90m. The test bench is presented in figure 5.

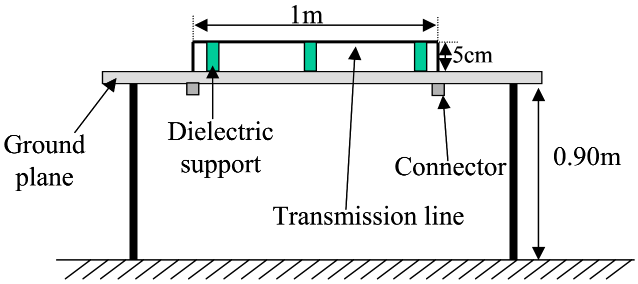

Figure 5 : The experimental test bench

All the measurements are performed with a network analyzer which output (Port 1) is connected to an amplifier. The input of the analyzer (Port 2) is connected the end of the harness where the measurement of the induced current has to be performed. The internal 50Ω of the input is used as the end load of the transmission line. The measurements presented in this paper cover the 1 MHz – 400 MHz frequency band. Figure 6 presents the measurement instrumentation applied to the DBCI test method.

All the results in this paper represent directly the transmission parameter S21 between the input and the output of the network analyzer. This transmission parameter corresponds to the coupling factor between the two ports of the network analyzer including the amplifier and the coupling facility (antenna, stripline, injection probes). Furthermore, there is no correction applied to the results (antenna factor, transfer impedance of the injection probes …) and the comparison of the different results are made on a relative basis rather than on an absolute basis.

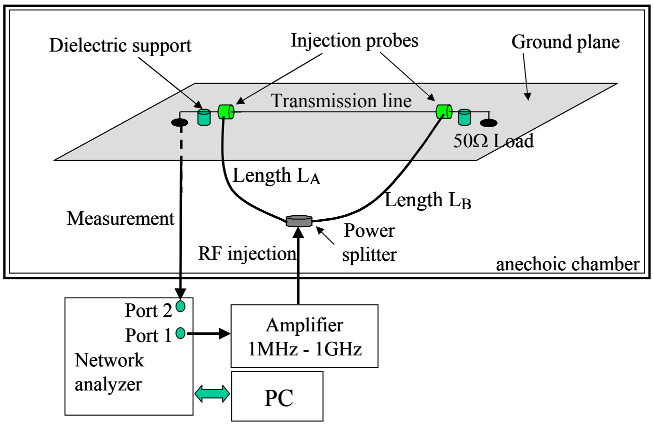

Figure 6 : DBCI experimental test bench and measurement equipment

3. Comparison between DBCI and anechoic chamber measurements

In order to carry out the experiments by the anechoic chamber method (figure 7), the output of the power amplifier feeds a biconilog antenna placed as far as possible from the test bench in order to reach far field conditions at low frequencies. The distance chosen is 4 metres from the position of the transmission line. This configuration creates a simultaneous coupling of the electromagnetic field normal to the transmission line.

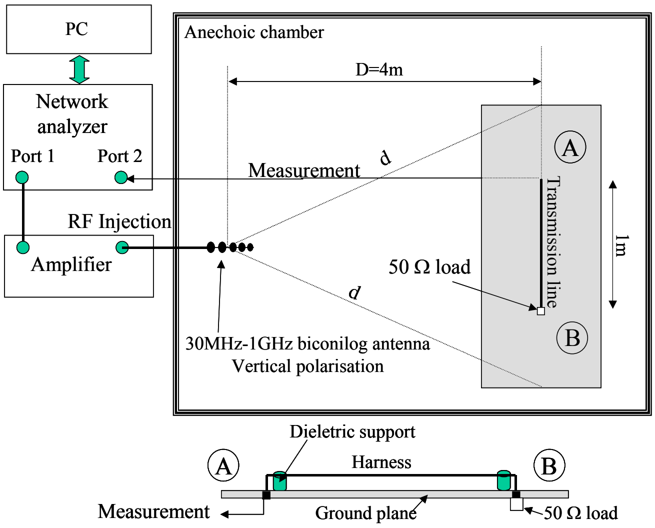

Figure 7 : Anechoic chamber test configuration

Figure 8 shows the coupling factor between the input of the amplifier and the load at the end (A) of the transmission line in the case of the DBCI and the anechoic chamber methods. Good agreements are obtained between the DBCI method, the anechoic chamber method and the simulation results (figure 4) if rescaled in amplitude. Nevertheless, and as mentioned in introduction, there is no correlation with the BCI results presented in figure 4. However, differences on the frequency minima around 300 MHz appear between the DBCI measurements and the simulation results. This is due to the fact that the transmission line equivalent length in the DBCI experiments is slightly shorter than 1 metre. Indeed, the harness length considered in the simulation (figure 4) and affected in the anechoic chamber method is 1 metre whereas the length that has to be considered in the DBCI experiments is the length between the centers of the injection probes, which is 0.865m.

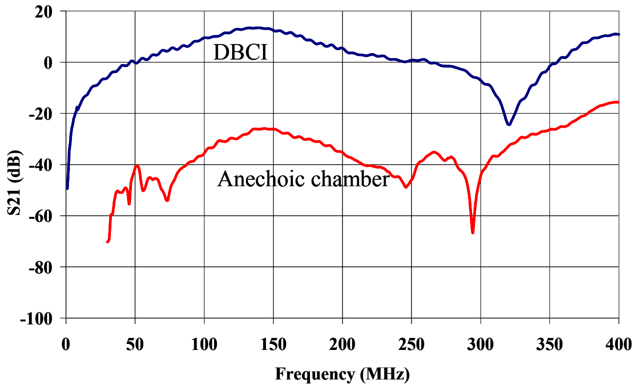

Figure 8 : Comparison between DBCI and anechoic chamber measurements

4. *Correlation between DBCI and stripline measurements*

For the measurements with the DBCI method, the test configuration is identical as previously except for the length between the cables feeding the two injection probes is different in order to create a progressive coupling.

In order to perform measurements with the stripline method (figure 9), a removable plate is added over the ground plane. The electromagnetic field is created by connecting the output of the amplifier to one of the ports of the stripline, the other port being connected to a 50Ω load. This configuration creates a progressive coupling of the electromagnetic wave along the transmission line.

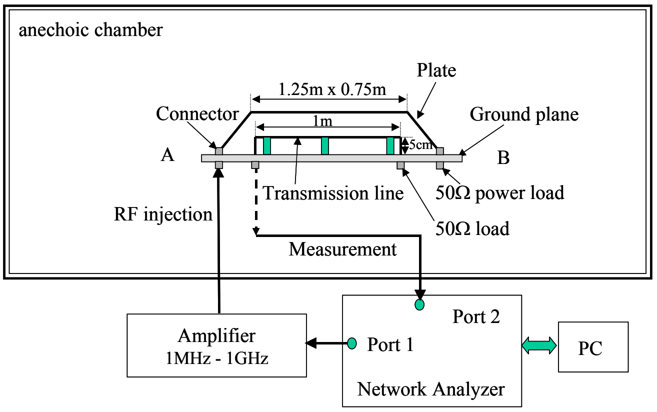

Figure 9 : Stripline test configuration

Figure 10 shows the coupling factor between the input of the amplifier and the load at the end (A) of the transmission line in the case of the DBCI and the stripline methods. As previously, good agreements are obtained between the DBCI method, the stripline method and the numerical simulation results (figure 4) if rescaled in amplitude. As previously, there is no correlation at all with the BCI method and remarks relative to the differences on the frequency minima appearing between DBCI measurements and simulation results are also applicable in this case.

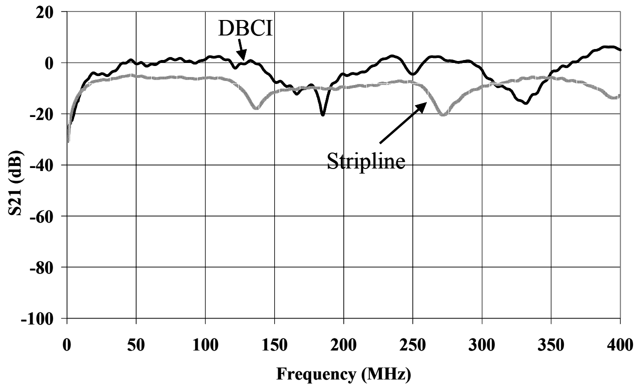

Figure 10 : Comparison between DBCI and Stripline measurements

5. *Conclusion*

Experiments presented in this section have demonstrated that acceptable correlation is obtained on the one hand between the anechoic chamber and the DBCI methods, and on the other hand between the stripline and the DBCI methods. A theoretical demonstration and measurements in [2,3] have also proven that correlation between the BCI method and the two others is rare. Nevertheless, there is also no correlation between the anechoic chamber and the stripline methods. This is principally due to the different coupling modes between the incident field and the harness. In the stripline, the electromagnetic wave arrives with a progressive coupling along the harness, whereas in the anechoic chamber, it arrives with a simultaneous coupling normal to the harness.

Three different solutions can be envisaged to obtain comparable results simultaneously by the three test methods.

The first solution is to create a progressive coupling in the anechoic chamber by turning the test bench by 90° around the vertical axis (figure 11). In this new configuration, the electromagnetic wave is coupled to the harness with the same direction and the same polarization as in the stripline method. Unfortunately, considering the distance D between the antenna and the beginning of the harness, the electromagnetic field decreases along the harness by $1/D^2$ and $1/D^3$ for low frequencies, which it is not the case in the stripline method. This is highlighted in figure 12, where the two different results are presented for extremities (A) and (B). Moreover, this requires to have another test configuration and to modify the test bench in the test facility.

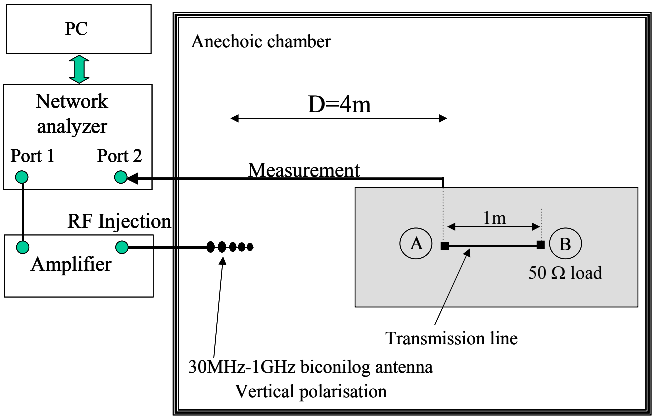

Figure 11 : Anechoic chamber test configuration – Progressive coupling

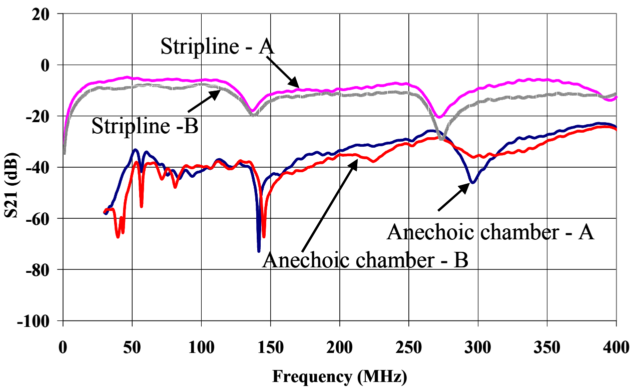

Figure 12 : Measurement in an anechoic chamber – Progressive coupling – Comparison between measurements on ends A and B

The second solution is to create a simultaneous coupling normal to the harness in the stripline. This solution requires a length of the harness shorter than the width of the stripline (in our case 0.75m), and would oblige one to impose the same length of harness in the two other test methods. For this reason, this solution cannot be envisaged.

The last solution consists in proposing for the three methods a new harness setup conserving a standard length of the harness but giving comparable coupling results.

II – A new harness setup

1. Coupling of a plane wave on a segmented transmission line

The background of the new harness configuration proposed in the following is based on the analysis of the coupling of a plane wave on a segmented transmission line as illustrated in figure 13. In this example that can be generalized, the transmission line is divided into several sections (A,B), (B,C) and (C,D). There is no particular geometrical proprieties between each section (angles …) or for each section (length …) as long as each segment can be considered as a stand-alone transmission line and that the coupling between transmission lines is negligible.

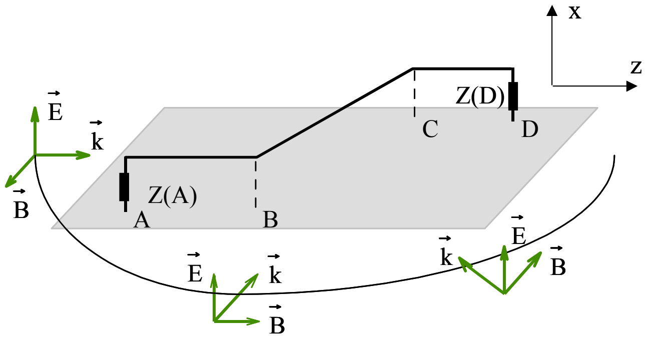

Figure 13 : Coupling to a segmented transmission line in the case of $E_z = 0$

If we then consider all the plane waves propagating in horizontal directions and polarized vertically (electric field) over an azimuth of 360°, we can easily replace each segment and its respective coupling by an equivalent circuit as defined previously in I-1. The global equivalent electric circuit summarizing the electromagnetic coupling on the entire segmented transmission line is given in the upper part of figure 14.

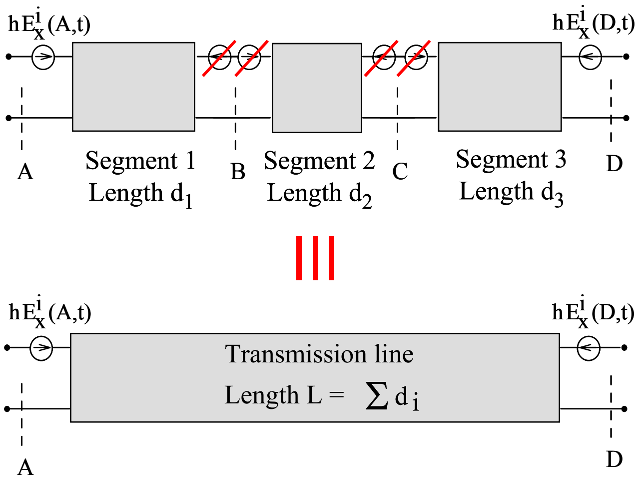

Figure 14 : Equivalent coupling sources

One can then notice that, at each junction between two segments, the induced equivalent voltage sources at each end of the sections cancel each other, leaving only the equivalent sources at each extremity (A) and (D) of the transmission line.

Therefore, given any vertically polarized plane wave coupling on a segmented transmission line, and assuming that each segment can be considered as a stand-alone transmission line and that there is no coupling between segments, the induced sources applied to the transmission line are only 2 voltage sources related to the electric field at each end of the transmission line whatever its length and its route.

Applying this equivalence principle, it is then possible to create on a 1 metre harness the same coupling in the stripline by placing the harness in a U shape as described in figure 15.

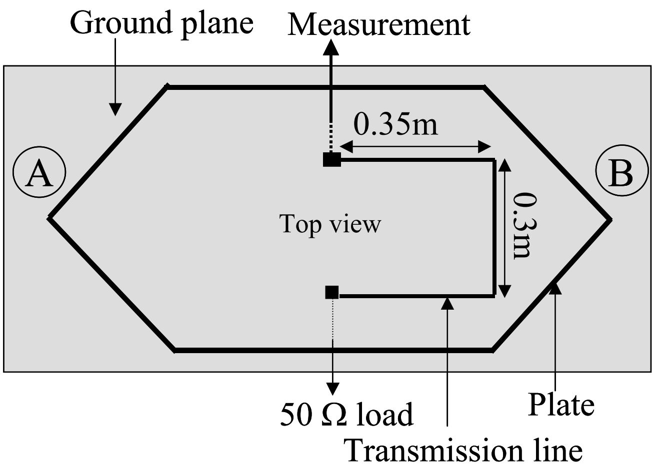

Figure 15 : Stripline test configuration – Simultaneous coupling – Transmission in U shape

2. Experimental validation

As the width of the stripline is 0.75 metres, the transmission line is broken into 3 segments placed symmetrically with regards to the propagation axis of the stripline. Furthermore, to avoid any coupling between segments, the parallel segments are separated by a significant distance. In this configuration, the two end segments are submitted to a progressive coupling whilst the central segment is submitted to a simultaneous coupling. Figure 16 gives the test configuration for the U-shaped transmission line in the case of the anechoic chamber method.

Figure 17 shows the comparison between the DBCI, the stripline, and the anechoic chamber results in the case of the conventional straight transmission line and the U-shaped transmission line. This comparison highlights that good agreement is obtained between the three test methods in the 1 MHz – 400 MHz frequency band if results are rescaled in amplitude, and for the same coupling configuration.

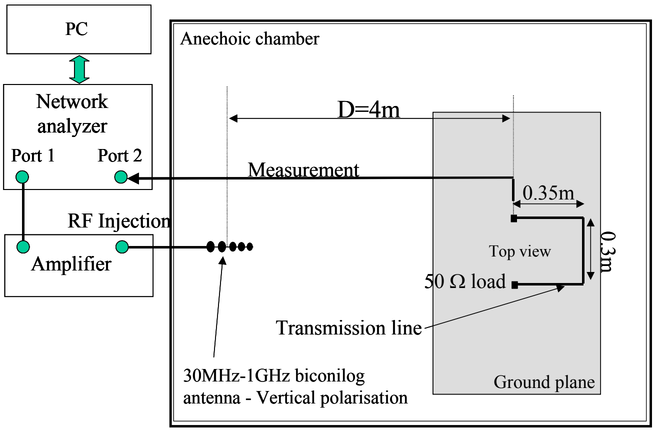

Figure 16 : Anechoic chamber test configuration – U-shaped transmission line

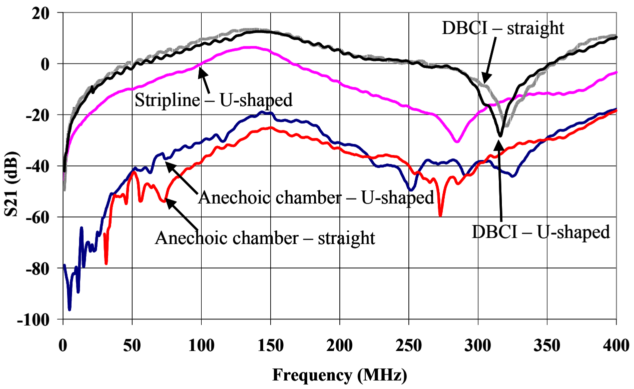

Figure 17 : Comparison between DBCI, stripline, and anechoic chamber measurements – Straight versus U-shaped transmission line

Conclusion

This paper proposes a new harness setup in a U shape which conserves the standard harness length of 1 metre required in the ISO BCI and anechoic chamber methods. The experimental validations given in this paper show that, by using this new harness setup, one can obtain, not only the same results as the conventional straight harness in the anechoic chamber method (compatibility with the existing standard ISO 11452-2), but also good agreements between the DBCI, the stripline and the anechoic chamber test methods in their common frequency bands and for the same coupling configuration. This is a very encouraging result signifying that these three entirely different test methods can lead to the same results for the study of the immunity of automotive electronic devices and that these results can also be compared to previously obtained results in the standard anechoic chamber method.

Nevertheless, future work has to be carried out to develop the DBCI calibration method in order to obtain the same scales and the same interference levels on the loads of the harness. It is also needed to improve the injection system in order to take into account the position of the injection probes and the effective length of the harness. At last, tests on real equipment have to be performed.

References

[1] ISO 11452 : *Road vehicles, electrical disturbances by narrowband radiated electromagnetic energy, component test methods* – 1995.

[2] M. Klingler, M. Szelag & M. Heddebaut : *Double Bulk Current Injection : A Possible Substitute to Field-to-wire Coupling* - EUROEM'94, Bordeaux, 30 mai - 4 juin 1994.

[3] M. Cuvelier, S. Ficheux, A. Maridet & M. Klingler : *Evaluation de la méthode de double injection de courant par rapport aux essais en cellule stripline et en chambre anechoique*, CEM 2002, Grenoble, march 2002.

[4] F. Rachidi : *Formulation of the Field-to-Transmission Line Coupling Equations in Terms of Magnetic Exitation Field* - IEEE Transactions on Electromagnetic Compatibility, Vol.35, N°3, August 1993.

[5] D. A. Hill : *Currents Induced on Multiconductor Transmission Lines by Radiation and Injection* - IEEE Transactions on ElectromagneticCompatibility, Vol.34, N°4, November 1992.