A simple Conducting Wire for Decoupling Neighbouring Antennas

Georges Da Silva, Philippe Besnier

To cite this version:

Georges Da Silva, Philippe Besnier. A simple Conducting Wire for Decoupling Neighbouring Antennas. EMC EUROPE BRUGE, Sep 2013, Bruge, Belgium. <hal-00870030>

HAL Id: hal-00870030
https://hal.archives-ouvertes.fr/hal-00870030
Submitted on 4 Oct 2013

A simple Conducting Wire for Decoupling Neighbouring Antennas

Georges Da Silva, Philippe Besnier
Université Européenne de Bretagne
I.E.T.R / INSA UMR 6164 CNRS
Rennes, France
Georges.da-silva@insa-rennes.fr

***Abstract*—This communication deals with the radio-electric compatibility of antennas installed on a same platform, more precisely, on a same wall plane. These antennas, associated with various communication systems on board a vehicle (such as a ship) have to be compact and installed in a limited area. Antennas's ground plane is a limiting factor since a too small one may limit antenna performances. On the other hand, antennas must be appropriately separated to avoid coupling between them. First, we examine the design of a compact ground plane of a monopole antenna and then of a patch antenna Then, this paper investigates the role of a simple conducting wire as a solution to decouple patch antennas without significantly influencing their radiation pattern.**

Keywords—radio-electric compatibility, antenna decoupling

I. INTRODUCTION

On board modern military ships, antennas have to be placed on the top side structure, made from metallic or composite materials. Composite materials are very attractive since it offers both ligthness and good resistance to the marine environment. This paper is dedicated to the installation of antennas on a wall surface made of composite material. In principle, it is required to install many antennas corresponding to various observation or communication systems. Therefore, one challenge is to use compact antennas that preserve their radiating performances once installed on the wall surface. On the other hand, the desire for reducing distances between antenna is challenging with regard to the decoupling requirements. One of the limiting factors for compacity of antennas is their own refererence or ground plane. This communication starts with the design of ground plane size of standard monopole antennas and classical patch antennas. This size defines the appropriate distance of such antennas with respect to the edge of the hosting surface. These aspects are described in section II of this paper.

In section III, we then discuss techniques that increase the decoupling between antennas and/or enable to install them closer to each other. This section only discusses the case of patch antennas since their antenna pattern induces a limited amount of coupled signal in the azimuth direction. However, since these antennas may have a limited ground plane whose edge effects may be non negligible, a decoupling solution must be found to avoid a far too large separation between them.

Looking for elementary solutions we propose to use a simple conducting wire rather than, for instance, a piece of absorbing material. We first discuss its simple theory of operation. Then, numerical simulation are performed and the results are discussed. Performance of such a decoupling wire associated with patch antennas is shown to be significant under some specific conditions. Some measurement results are reported.

II. COMPACTNESS OF MONOPOLE ANTENNAS OR PATCH ANTENNAS

A. *Compacity of a monopole antenna*

The monopole antenna is the most simple antenna structure but still in use for some communication systems. The theory of radiation of a monopole antenna supposes an infinite ground plane. Hopefully, in practise, only a ground of limited size enables i) to match the antenna at the intended tuned frequency of the quarter wavelength antenna ii) to consider that the main antenna radiation is consistent with theory, although it may produce some secondary radiation lobes.

The classical scientific litterature provides several equivalent models of a dipole or a monopole antenna, which are valid around the antenna tuned frequency [1]. We refer to the Chu model as described in [2] where a monopole antenna is described as a lumped element circuit composed of a capacitance in series with a resistance and an inductance in parallel. For a monopole antenna over an infinite ground plane this capacitance, labelled C_0 is given by [1] :

$$C_0 = 2\frac{27.82h}{\ln(2h/a) - 1.693}(pF) \tag{1}$$

In this equation, h is the height of a cylindrical monopole and a its radius. Of course, C_0 in combination with the inductance L defines the tuned frequency of the monopole antenna. On the other hand, the same parameter may be also associated with the imput impedance of the antenna for frequencies much lower than the tuned one. A simple numerical approximation of (1) is provided by assuming the monopole antenna as a non uniform transmission line as depicted in Figure 1. The calculation of the imput impedance of such a transmission line of length h, at a much lower frequency (about one tenth of the tuned frequency) gives a result very close to (1). It suggests and confirm a well known engineering practise, i.e. the size of the ground plane must be at least equal to h squared.

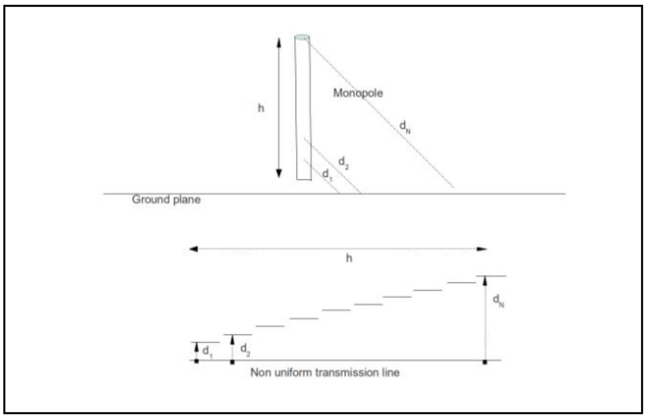

Fig. 1. A monopole antenna and its equivalent transmission line model for calculation of it input capacitance.

B. Compactness of a patch antenna.

The previous result may be used for assessing the size of the patch antenna ground plane using the same principle. We indeed admit that such an electric antenna may also be depicted by the same type of equivalent circuit as a monopole antenna. Adjusting the ground plane size then consists in evaluating its minimum size that corresponds to an asympotic value of C_0. In that situation, the intented tuned frequency is therefore reached.

To do so, we use the Feko software package to design a patch antenna, according to standard textbooks [3] intended to operate at 500 MHz and perform a series of imput impedance computation at a much lower frequency (i.e. a much less time consuming calculation for a method of moment solver) typically 50 MHz. Numerical results show that the ground plane size may be chosen to be around two times the size of the radiating patch.

III. A DECOUPLING DEVICE BETWEEN TWO PATCH ANTENNAS

The patch antenna ground plane has been limited in size. Although its size is sufficient to reach a satisfying radiation behavior, the antenna pattern in the azimut plane exhibits non negligible values of radiated field, due to the ground plane edge effect. Therefore, it may prevent from placing two patch antennas too close from each other specifically for high decoupling requirements, say 50 dB for instance.

We now install two of these patch antennas at a distance from each other on the same surface as depicted in Fig. 2. Given the example of the above patch at 500 MHz, one reach a 50 dB decoupling target at a long distance of about 6.7 wavelengths. This distance was estimated from a free space propagation point of view, given the calculated radiation pattern of the patch antenna in the azimut direction. This radiation pattern was simulated through the Feko sofware package used throughout this study.

Between the two patch antennas, Fig.2 shows a cylindrical wire whose length is about λ. It is intended to be placed at half-distance between the two antennas to provide an increasing decoupling factor between antennas without significantly modifyng their performance. We provide a simple and approximate theory for this device operation.

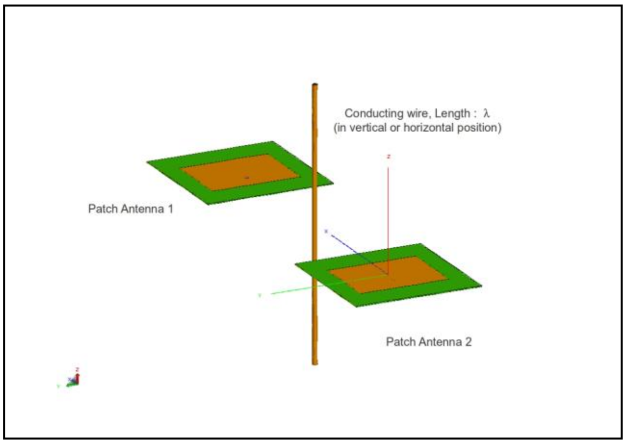

Fig. 2. Two patch antennas and a conducting wire as decoupling device (in vertical or horizontal position).

A. Approximate theory of operation

The conducting wire is placed in a direction with respect to antennas which does not correspond to the main radiation lobe of antennas. Therefore, it will certainly influence the radiation pattern but only a limited impact is expected. The case of a vertical conducting cylinder is however a less convenient solution with regard to this criterion. The orientation (vertical or horizontal..) has to do with the polarization of the antenna radiation in that direction. The most convenient orientation would be that of a maximum induced current on the cylindrical wire.

The operational principle is then the following. The current induced on the wire will produce a scattered field in reaction of the excitation field that propagates in direction of the receiving antenna. Since the cylindrical wire is not loaded, it radiates most of the incoming wave. At the receiving antenna, the total incident field may be seen as the superposition of the radiated field from the transmitting antenna and of the scattered field from the cylindrical wire. A compensation may occur if the distance between antennas is close enough so that the scattered field is significant with respect to the direct illumination.

From very simplifying assumptions we may derive an analytical expression for the field attenuation. Considering free space propagation in the far field, we may establish that the two signal contributions at the receiver are given by equations (2) and (3).

$$P_{TWR} = \frac{\lambda^4}{(2\pi D_{ant})^4} G_T G_W^2 G_R P_{inj} \qquad (2)$$

$$P_{TR} = \frac{\lambda^2}{\left(4\pi D_{ant}\right)^2} G_E G_R P_{inj} \qquad (3)$$

In these equations P_{inj} is the injected power to the transmitting antenna, G_T, G_W and G_R are respectively the gain of the transmitting antenna, the gain of the wire, and the gain of the receiving antenna, in the appropriate line of sight direction and in the polarization of the wire. Equation (2) comes from the hypothesis that the wire is a perfectly electric condutor, i.e. it has no losses at all. The gain of the wire is squared since it acts both as a receiver and a transmitter. The wire gain is equal for both situations due to symmetry.

However these signals are combined in field amplitude and phase. Therefore, given the field is homogeneous to the square root of the power, the attenuation coefficient, A, for the field is given by :

$$A = 1 - \sqrt{P_{TWR} / P_{TR}} = (1 - \frac{\lambda}{\pi} \frac{G_W}{D_{ant}}) \qquad (4)$$

This atttenuation factor is only valid in far field conditions and must be used with care for too close distance between antennas. However, equation (4) evidences that such a wire is a pertinent solution for limited ditances between antennas. Applying equation (4) supposes that the gain of wire in the light of sight of antennas is also known. The exact gain depends on the current distribution on the wire. Given the length of a wire which is chosen to be equal to a wavelength, the numerical value for the estimation of A is chosen to be 2.5.

A plot of A as a function of the distance is given in Fig.3.

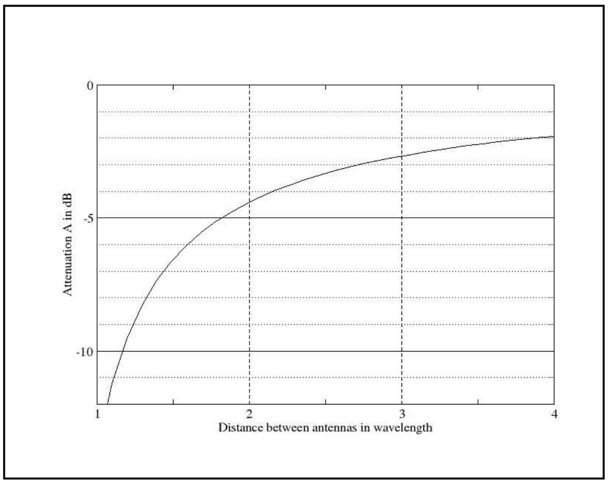

Fig. 3. Theoretical Attenuation (A) provided by a conducting wire inserted between two antennas for a wave propagating in a linear polarization and parallel to the wire axis in free space and far field approximations.

A preliminary experimental investigation was carried out on simple monopole antennas installed on large ground planes. Since the monople rod is in vertical position the radiation may be considered as purely vertical in the azimut plane. The monopoles are tuned at 1440 MHz and distance between antennas is adjusted at 1.5 λ; 2 λ and 4 λ.

If the wire is positionned in horizontal position between antennas, there is only a negligible attenuation recorded when measuring the transfer function with a vector network analyser (VNA) between both antennas. This result was expected. In a vertical position, the recorded attenuation at distances of 1.5 λ, 2 λ and 4 λ are respectively 7 dB , 8 dB and 3 dB. These values are in the order of magnitude of the theoretical ones and suggest that the far field conditions are not fullfilled for the two first positions. At small distances this wire implies a modification of the antenna pattern and may even detune the antenna. With this respect a distance around 2 wavelength between two antennas is probably a good trade off.

B. *Numerical investigations and validation with patch antennas.*

In the following section we investigate if such a wire solution is an adequate solution for decoupling patch antennas. As far as patch antenna are concerned they can be associated on a same wall in different relative orientations. However, this orientation will be in general dictated by the operational conditions and not driven by electromagnectic compatibility questions. Fig. 1 depicts in fact the conditions in which antennas are oriented in the same direction.

- Results for a vertical wire

A vertical wire seems to be well fitted to such situation since the polarization is mainly along the elevation angle. This is however not so true in the azimut plane since, the radiating field in that direction is vertically polarized along the equivalent transmission line direction of the patch and horizontally polarized across that direction. The wire is situated in the direction of the transmission line direction of the patch and therefore the vertical orientation seems to be well suited.

Feko simulations have been carried out for different distances. Numerical attenuation for a distance of 2 wavelengths is about 8 dB whereas this attenuation is reduced to 4 dB for a 3 wavelengths distance. Those two situations correspond to a decrease of about 2 dB at 2 wavelength distance and of about 1 dB at a distance of 3 wavelength of the maximum gain of the antenna.

Below a distance of 2 wavelengths the antenna pattern is considered to be too significantly modified by the presence of the wire.

- Results for an horizontal wire

Since the wire length is about a wavelength and may be situated at a short distance from the patch antenna, we may think that an horizontal wire would be sensitive to some residual but no negligible radiation in the horizontal polarization. Such a situation would be more pratical, since it is much easier to implement on a wall plane.

The simulation of the transfer function between antennas gives a negligible attenuation for the distance of one wavelength between antennas. However, the attenuation yields 10 dB for the two wavelength distance. Accounting for the loss in efficiency of the antenna (the maximum gain of the antenna presents a 3 dB reduction) the decoupling factor is overall of about 7 dB. In this situation, the two antennas are decoupled in the same manner as if they were distant from more than six wavelengths.

Fig. 4 enables to check that even in the E-plane the shape of the radiation pattern is acceptable , although more affected at a distance of only one wavelength between antennas.

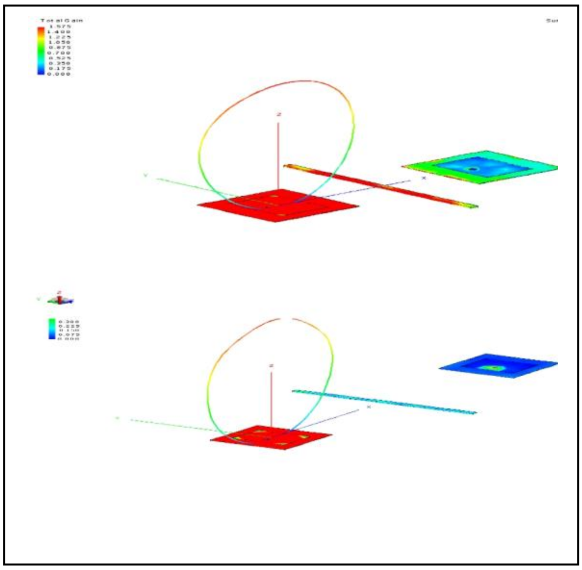

Fig. 4. Modification on the E-plane radiation pattern in the presence of an horizontal wire. Distances between antennas are 1λ (upper graph) and 2λ (lower graph).

IV. EXPERIMENTS

For practical reasons we use two patch antennas tuned to 1.9 GHz. These two antennas are fed through a coupling slot supplied by a microstrip track inserted below the slotted ground plane. The size of the ground plane is about two times the patch size. The radiation pattern of the two antennas have been measured. It turns out that the maximum gain of the antennas are about 5 dB for one antenna and 4 dB for the second one. The two antennas are (one is in copper the other is made of carbon fiber) not technically identical but it is out of the scope of this paper and without any consequences on the following results. The carbon fiber slot-patch antenna was inspired from [4] and achieved by its main author. In the azimut direction, the gain may reach about -8 dB under horizontal polarization

These two antennas are installed in reciprocal directions of each other that correspond to this gain measurement of -8 dB under horizontal polarization. In these circumstances, a cylindrical wire in the horizontal position seems to be well suited to decouple these two antennas.

Rather than installing these two antennas in a controled environment such as in an anechoic chamber or a reverberation chamber, we install these antennas in an indoor environment to perform measurements in a simple way and maybe in a more realistic situation.

The two antenna ports are connected to a VNA and the S21 parameter is measured successively for two situations. The first one consists in measuring the coupling level between antennas without any decoupling devices. The second situation corresponds to the same tranfer function measurement when the cylindrical piece of wire is inserted. The cylindrical wire is 18 cm long (about 1.1 wavelength at 1.9 GHz) and a diameter of 2 mm. Various antenna distances are then tested, but the cylindrical wire remains at half-distance.

As a first general statement, the results show that the theory seems to be too optimistic. It does not come to a surprise since, the coupling between these patch antennas cannot be restricted to one polarization only.

However a significant effect was observed for short distances between antennas. Numerical results in section III suggests that this decoupling effect may vary a lot at short distances and completely disappear at long distances.

Without performing an exhausting set of positions, we found an interesting result at a distance of 1.4 wavelength at 1.9 GHz (22 cm between antennas) and inserting the cylindrical wire at half distance. Fig.5 illustrates these results. The coupling pattern is provided in the 1850-1950 MHz frequency range This pattern fluctuates a lot in this bandwidth due to the multipath propagation channel in the indoor environment of the lab that includes a Faraday cage nearby. The pattern shape is not modified if a cylindrical antenna is set up between antennas. Its contribution to coupling attenuation is clear. This coupling attenuation reaches only 2 dB for the highest value of coupling since other contributing coupling paths are presents. But it goes up to 10 dB in the situation where the direct coupling between antenna is predominant.

A comparison is made with the insertion of a piece of absorber (length 20 cm width 5 cm, and height 1 cm) substituting the wire (Fig. 6). It is clearly seen that this rather sophisticated solution is less efficient than the simple metallic structure. We could of course reach the same performance with the optimization of the size and nature of the absorber (here a piece of C-RAM MT 30, Cuming Microwave). Observation of the results show that, although the wire and the piece of absorber use very different principles they do act in a very similar way as a function of the predominance of the direct coupling path between antennas.

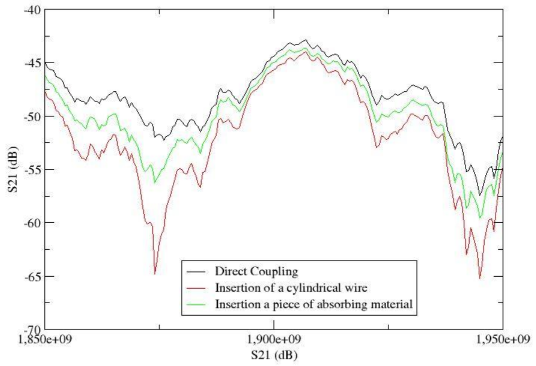

Fig. 5. Coupling transfer function as a function of frequency (1850-1950 MHz) between two patch antennas in indoor environmment. Distances between antennas is 1.4 λ . Either a copper wire or a piece of absorber is used as a decoupling device. Comparison is performed with the direct coupling situation.

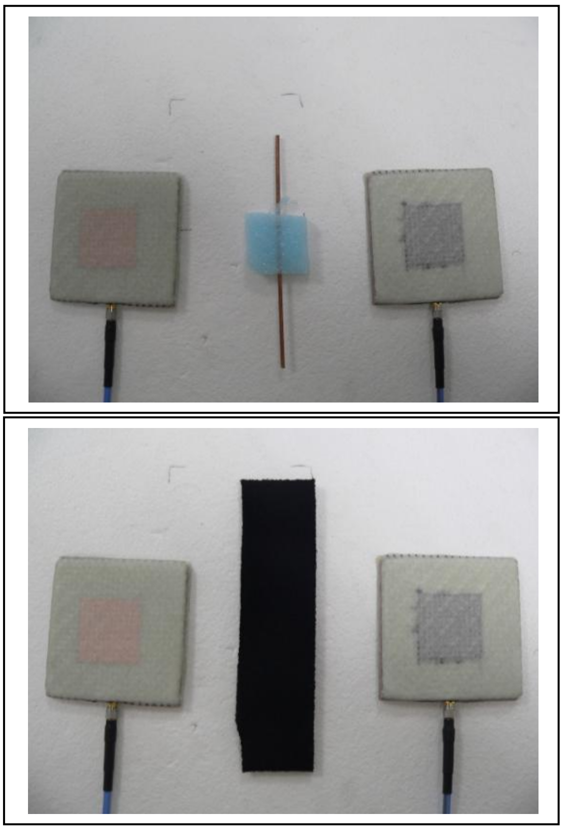

Fig. 6. Photo of the two antennas with a cylindrical wire or a piece of absorber as a decoupling device.

V. CONCLUSION

This paper was dedicated to an analysis of integration and radio-electric compatibility between neighbouring antennas sharing the same plane support. A preliminary analysis enables to roughly estimate an as compact as possible ground plane for a monopole antenna and then for a patch antenna.

Given such patch antenna with a limited ground plane, we studied the decoupling performance of a bare conducting wire inserted between two of them. From a simple theory we establish that such a simple device could enhance, in some conditions, the decoupling between antennas. The coupling path between antennas may indeed significantly modified if antennas are not too far apart (typically less than 3 wavelengths). The closer are the two antennas the better would be this solution as long as antennas operate in normal conditions (no modification of antenna pattern and matching profile). This type of solution is obviously very dependent on the incident field polarization.

Some preliminary experiments with a monopole antenna confirmed the analysis. Experiments were also carried out with more realistic planar antennas installed on a same surface. Indoor measurements shows that it was possible to significantly enhance the decoupling level. An illustrative comparison with a piece of absorber confirmed this effect.

Future works will be dedicated to further experimental investigations and comparison with different decoupling techniques. Attention will be paid in the future to the influence of a conducting backplane associated to the supporting composite material.

ACKNOWLEDGMENT

This work was partially funded by the french “Fond Ministériel Unifié’ for competitiveness clusters. More specifically, it is carried out in the frame of the collaborative project named SAMCOM chaired by DCNS and supported by the EMC2 cluster. The authors would like to thank the partners of SAMCOM (DCNS, Thales, CERPEM, CEMCAT and Plastima) for fruitfull discussions. Special thanks to Lilia Manac’h at I.E.T.R. who designed and manufactured the patch antennas.

REFERENCES

[1] T.G. Tang; Q.M. Tieng,M.W. Gunn, “Equivalent Circuit of a Dipole Antenna Using Frequency Independent Lumped Elements ,” IEEE trans. on EMC, vol. 41, n°1, Jan. 1993, pp 100-103.

[2] C.J. Chu, “Physical Limitations of Omnidirectional Antennas,”, J. Appl. Phys., vol. 19, Dec 1948, pp. 1163-1175.

[3] C.A. Balanis, Antenna theory :analysis and design. 3rd Edition, John Wiley and sons, 2005.

[4] L. Manac’h, X. Castel, M. Himdi, “Performance of a Lozenge Monopole Antenna Made of a Pure Composite LaminatePIER Letters, Vol. 35, 115–123, 2012”