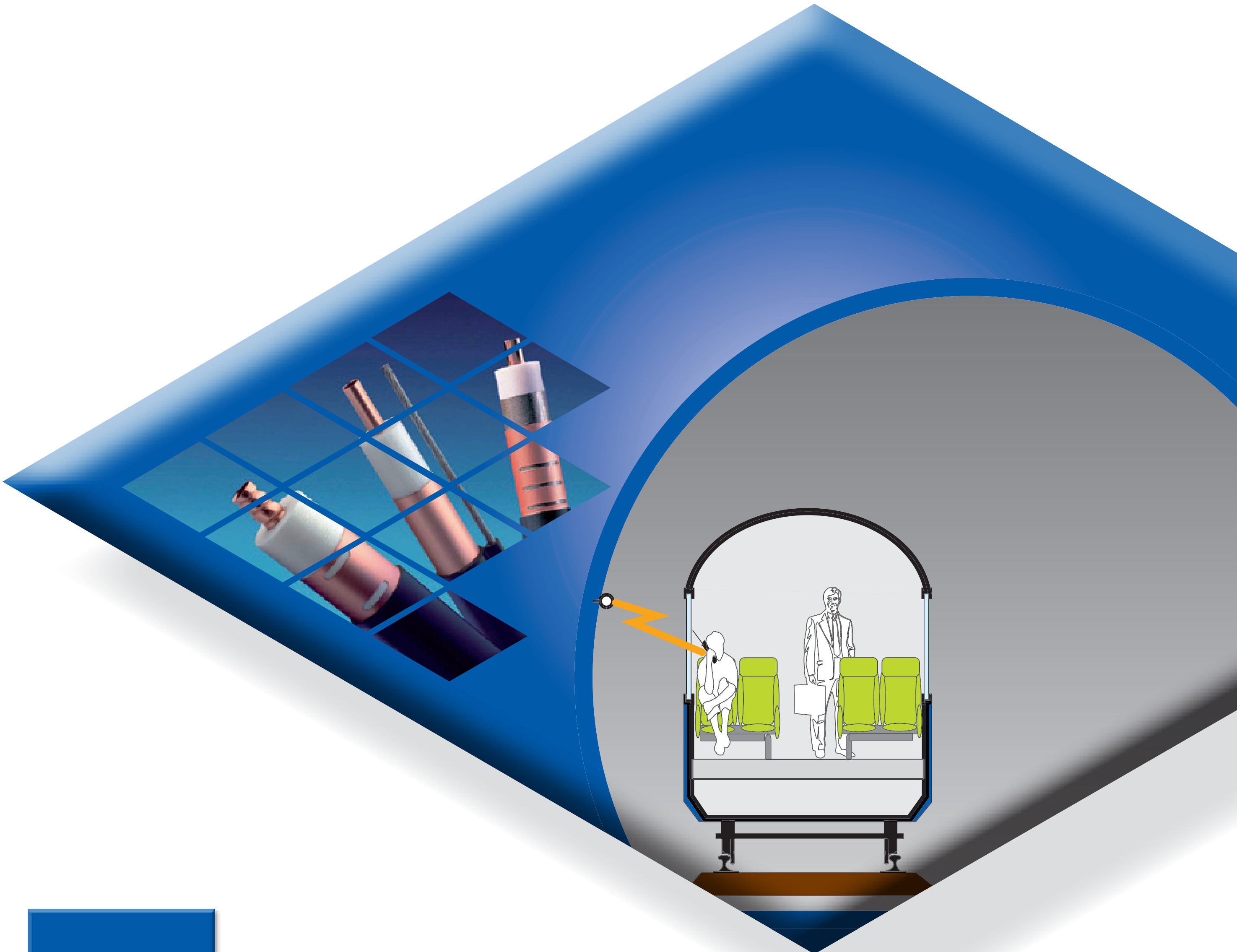
# RADIATING CABLES

## *Application note*



Kabelwerk EUPEN AG cable

EUPEN

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| List of abbreviations | |
|---|---|
| CL | designates a coupling loss in general, whichever the orientation and the probability level (50%, 95% or any other percentile). |
| CL50% | median value of the coupling loss. |
| CL95% | 95% percentile of the coupling loss. |
| CLr, CLp and CLo | In the context of § 3.2 and 4.2 only, these symbols designate the CLs in the radial, parallel and orthogonal orientations respectively, whichever the probability level. These abbreviations have not been used every where to simplify the mathematical formulas. |
| CLmean | In the context of § 3.2 and 4.2 only, this symbol corresponds to the mean CL averaged over the three antenna orientations as define in the standard. |
| RC | radiating cable. |

# INTRODUCTION

The aim of this application note is to provide useful information for:

- → the performances optimisation of the Eupen radiated mode cables;
- → reliable link budget;
- → RC performances comparison.

Section 1 and 2 include a brief reminder of some important definitions How to perform a link budget calculation is explained in section 3.

The radio engineers familiar with the RC subject have certainly noticed that there is a real lack of harmonisation concerning the definitio  of the coupling loss. Indeed, documents such as data sheets and application notes published by the RC manufacturers reveal differences of interpretation that may lead to significan  errors in link budget or when the RC performances have to be compared. These differences are rather surprising as all the RC manufacturers refer to the same IEC standard.

The various methods to measure the coupling loss are presented in section 4. Its sensitivity to antenna orientation and other parameters is deeply analysed. Such an information may be useful for link budget calculations.

Some rules allowing optimisation of RC performances are also presented in section 5.

# 1. LONGITUDINAL ATTENUATION AND COUPLING LOSS

From the electrical point of view, RC performances are mostly characterised by the longitudinal attenuation (in dB/100 m) and by the coupling loss (in dB).

The **longitudinal attenuation** is a measure of the attenuation of the signal propagating inside the RC. It is specifie  in dB per unit length (usually in dB/100 m) and is given by the following formula:

$$\rightarrow a = 10\log \frac{P_{in}}{P_{out}}$$

where $P_{in}$ and $P_{out}$ are the RC input and output powers respectively.

The longitudinal attenuation is primarily the results copper and dielectric losses and amount of radiated energy. The longitudinal attenuation increases with the frequency and decreases with the cable diameter. It is also somewhat influence  by the proximity of the RC to other surfaces.

The **coupling loss** (CL) characterises the coupling between the energy travelling inside the RC and a receiving antenna. It is define  as the ratio of the received power at the antenna output to the power fl  wing in the RC. For example, if the power fl  wing in the RC was 0 dBm and the power received by the antenna was – 60 dBm, then the CL would be 60 dB. In the data sheet, the CL is given for an RC to antenna distance equal to 2 m.

The local value of the CL is given by the following formula:

$$\rightarrow CL = 10\log \frac{P_{cable}}{P_{antenna}}$$

where $P_{cable}$ is the power inside the RC (near the antenna) and $P_{antenna}$ the power at the antenna output.

Usually, CL50% and CL95% are specifie in the RC data sheets. Their meaning is illustrated in Figure 1. The curve represents the profil of the signal (in dBm) received by an antenna moved along a path parallel to the RC, for example at 2 m. The horizontal line at the top of the diagram represents the power (in dBm) inside the RC. The distance (in dB) between the horizontal line and the curve is equal to the CL at this particular point. The CL50% corresponds to the 50% percentile or median value. It means that 50% of the measured local values are lower and 50% are higher.

The CL95% corresponds to the 95% percentile. It means that 95% of the measured local values are lower than this figu e.

The CL measurement methods according to the IEC standard are detailed and analysed in section 4.

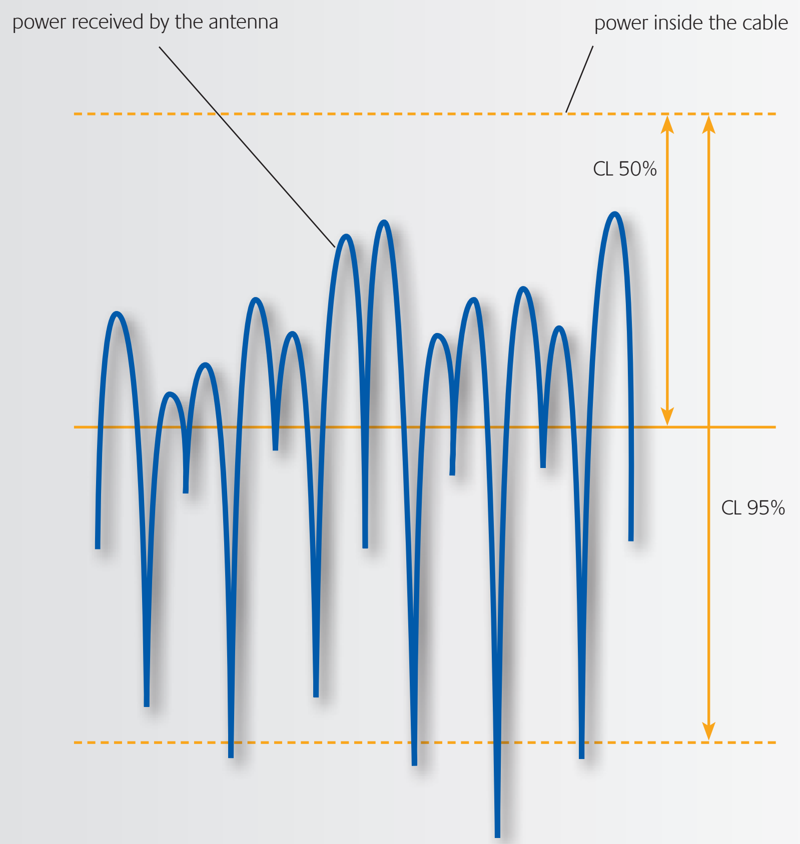



Figure 1:
CL50% and CL 95%
definition

# 2. RADIATED AND COUPLED MODE CABLES

All of the different types of RCs are based on the effects of spherical waves excited by the leakage produced by the apertures in the external conductor. The resulting fiel at a certain distance is given by the vector addition all of the apertures contributions. The Figure 2 shows a simple case where the electromagnetic waves generated by only three apertures are considered. These waves are identifie by the symbol W1, W2 and W3. Let's consider the resulting electromagnetic fiel at a point P.

The vectors E1, E2 and E3 in Figure 3 represent the electric fiel component at this point P corresponding to W1, W2 and W3 respectively. The vector E is their resultant. Without special precautions, the aperture contributions may give rise to destructive interferences at some places with a low resulting fiel indicated by a relatively short vector as shown in Figure 3 (left side). Conversely, aperture contributions may be in phase at other places, which give rise to constructive interferences, hence a strong resultant as shown in Figure 3 (right side). It is clear that the rationale in Figure 3 applies to both electric and magnetic fiel components.

The real situation is obviously more complex as the electromagnetic fiel at any point is the results of more than 3 apertures contributions. The rationale is however identical and it explains the fluctuation of the fiel strength along the RC. Typically, these fluctuation reach 20 to 30 dB peak to peak and can be modelised by a Rayleigh distribution. Usually, the difference between CL95% and CL50% ranges between 10 and 13 dB.

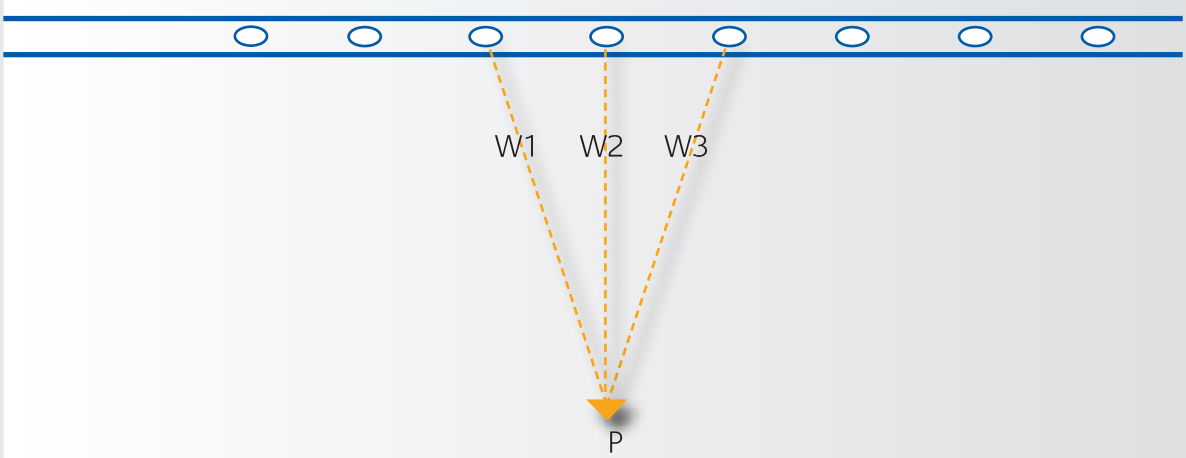



Figure 2:
Electromagnetic waves due to the apertures in the external conductor

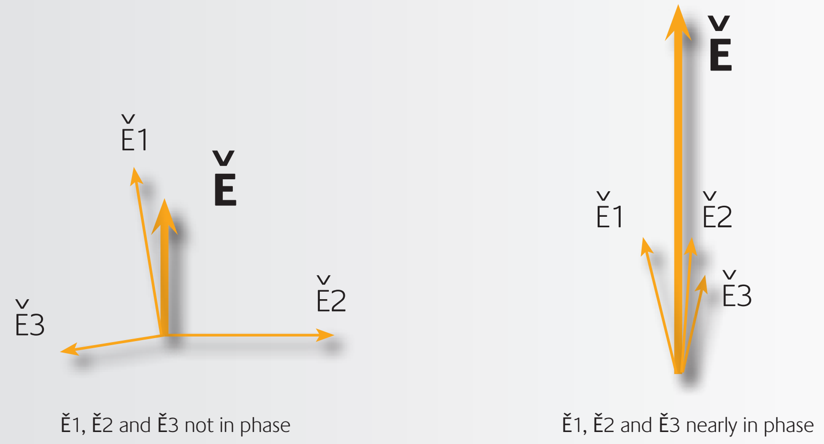



Figure 3:
Aperture contributions
out of phase (left)
and in phase (right)

The **radiated mode** RCs are designed to produce a coherent interference of the different apertures contributions in certain frequency bands and at all places around the RC. This effect is obtained if the aperture spacing is chosen in such a way that all the aperture contributions add up in phase in the RC radio coverage area as shown in Figure 3 (right side). This is achieved if the delay between the contributions of two successive apertures is a multiple of the signal period. When this condition is satisfied the resultant fiel is stronger and the fiel strength fluctuation along the RC length are considerably reduced. It results that:

➔ the CL50% decreases;
➔ the difference between CL95% and CL50% decreases and typically ranges from 3 to 8 dB.

With radiated mode cables, the main difficult is to maximise the frequency band in which the apertures contributions interfere in a coherent way.

All the radiated mode RCs work in coupled mode below a certain frequency, hereafter termed **“transition frequency”**. This transition is linked to the aperture spacing. This is because it is impossible to keep the different apertures contributions in phase when the wavelength exceeds, approximately, two times the distance between two successive aperture groups. However, the performances may be impaired, for various reasons, in some frequency bands above the transition frequency. This means that the radiated mode is not necessarily “superior” than coupled mode.

The Eupen radiated mode RCs are designed to provide low CL and low fiel strength fluctuation in several frequency bands allocated to most mobile radio systems standards such as TETRA, TETRAPOL, GSM 900, GSM R, GSM 1800, PCS, DECT, UMTS, WiFi (either at 2.4 GHz or at 5 to 6 GHz), WiMax, etc.

# 3. LINK BUDGET

The basic elements to calculate a link budget can be illustrated by considering the example shown in Figure 4. It involves a GSM 900 radio coverage in a dual-bore tunnel that is 900 m in length. It shall be assumed that:

- the power per channel available for the down link is 1 W (+30 dBm);
- the RC in each bore is fed via a power splitter ("T-feed" configu ation) the insertion loss of which is equal to 3.5 dB;
- jumper cables are used to connect the repeater, power splitter and the RCs. Their total insertion loss is equal to 1.5 dB;
- the specificatio imposes a received signal (measured with a half-wave dipole antenna) of at least -88 dBm at 95% of the points in the vicinity of the cable end and at 6 m distance.

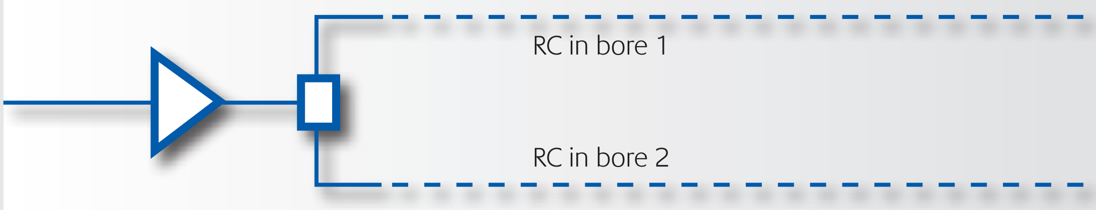



Figure 4 : Dual-bore tunnel with one base station and a power splitter

It shall also be assumed that the RC has the following characteristics at 960 MHz (upper limit of the GSM 900 frequency band):

- longitudinal attenuation: 3.1 dB/100 m;
- CL50% and CL95% equal to 58 and 62 dB respectively.

Table 1 summarises the link budget. The last line indicates that the specificatio is satisfied i.e. a minimum received signal (measured with a half-wave dipole antenna) higher than -88 dBm at 95% of the points in the vicinity of the cable end and at 6 m distance. The various lines of this link budget are commented here after.

Uplink performances (i.e. from mobile station to base station) can be computed in the same way.

| Table 1: Link budget example | |
|---|---|
| Available power per channel | + 30 dBm |
| Jumper cable loss | - 1.5 dB |
| Power splitter insertion loss | - 3.5 dB |
| RC insertion loss: 900 m with 3.1 dB/100 m | - 28 dB |
| CL95% at 2 m = 62 dB | - 62 dB |
| Correction for longer distance = 20 log (d/2) = 20 log (6/2) = | - 9.5dB |
| Penetration loss* | 0 dB |
| Mobile antenna loss relative to dipole* | 0 dB |
| Safety margin | - 10 dB |
| **Minimum received signal at 6 m from the RC (95% percentile)** | **- 84.5 dBm** |

* Note: It results from the specificatio of this particular example that the penetration loss and mobile antenna loss relative to dipole are equal to 0 dB.

## 3.1. RC insertion loss

The RC insertion loss is equal to the cable length multiplied by the longitudinal attenuation. This longitudinal attenuation is somewhat influence by the stand off distance (between the RC and the wall or ceiling to which it is hung). For example, if the RC is directly against a concrete surface, the impact on the longitudinal attenuation is frequency dependent and is obviously not identical for all RCs. If the IEC standard conditions are considered as reference values, measurements carried with various Eupen RMCs indicate that installing the RC directly against a concrete surface involve the following longitudinal attenuation increases:

- below 300 MHz, the impact is negligible and even sometimes negative;
- typically ranges from 5 to 10 % around 450 MHz;
- typically ranges from 10 to 20 % around 900 MHz;
- typically ranges from 25 to 60 % around 2000 MHz.

The longitudinal attenuation is also influence by humidity and dust deposit on the RC jacket. Even in rather severe conditions, the longitudinal attenuation increase never exceeds 10 %.

## 3.2. RC Coupling loss

Some RC manufacturers use the free space method or specify the CLs for the antenna orientation corresponding to the best result. The differences of interpretation in the meaning of the CL parameter may lead to significan errors in link budget or when the performances of different products have to be compared.

The CL50% and CL95% specifie in the Eupen data sheets are measured with the ground level method according the IEC 61196-4 standard[1]. The ground level method has been preferred because it define conditions which are closer to those actually met in practice. Indeed, in almost all the applications, the RC is hung at short distance from a surface (ceiling or wall). A detailed analysis of this issue is presented in section 4.

However, CLs measured with the free space method are also available for some Eupen RCs.

The CL50% and CL95% specifie in the Eupen data sheets are averaged over three antenna orientations (radial, orthogonal and parallel). As explained in section 4.2., the CL50% or CL95% that should be used for link budget correspond to the symbols CL50%-mean or CL95%-mean.



[1] IEC 61196-4 standard - Coaxial communication cables - Part 4: Sectional specificatio for radiating cables.

## a) E.M. wave depolarisation due to reflection on obstacles

In the case of communications with hand-held mobile equipment on board train, a wave penetrating into a carriage experiences reflection on the carriage walls, ceiling, floo , seats, etc. At each point, the fiel strength is the vector addition of several waves and the polarisation of the sum can be considered as elliptical rather than linear. Figure 5 shows the simple case where a direct wave radiated by the RC interferes with another wave which has been reflec ed by the carriage ceiling and window. The dashed arrows (at right angle with the direction of propagation) indicate the wave polarisation. If we consider the difference of propagation delay, it is clear that the polarisation of the resulting E.M. fiel at the reception point R is very complex. Figure 5 is a very simple case with only one reflec ed wave. In practice, the situations are much more complex as suggested in Figure 6 where the direct wave may be blocked by travellers or by another train.

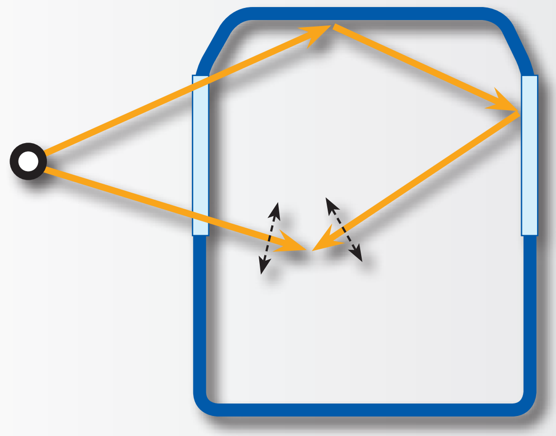
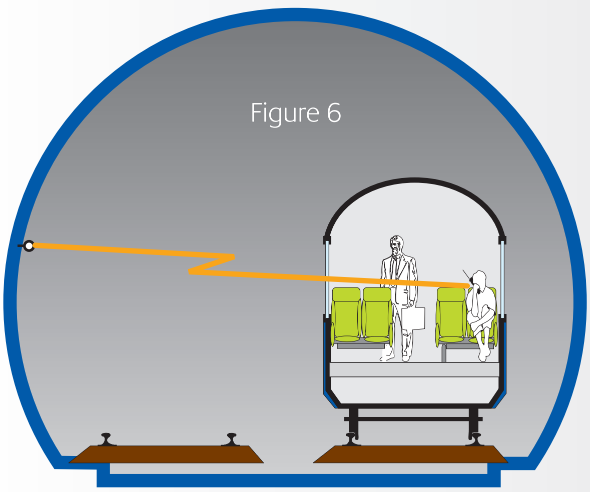


Figure 5:
Wave depolarisation
due to reflection

## b) Mobile antenna orientation

With hand-held equipments, the mobile antenna orientation is neither perfectly vertical nor horizontal but rather a combination of these as shown in Figure 7. Indeed, in normal use, an hand-held equipment is slightly down-tilted and not necessarily orientated for maximum response.



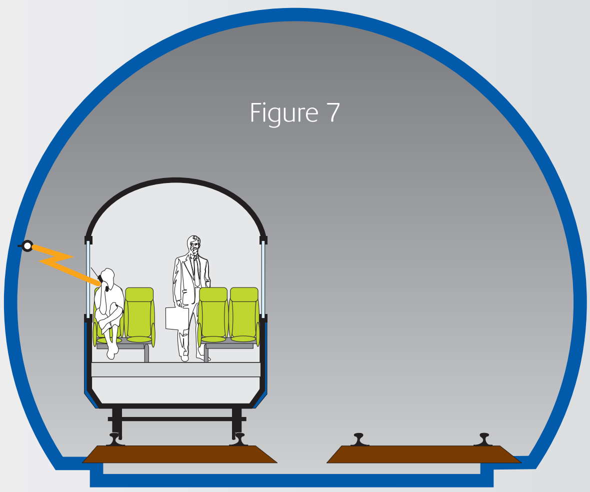




Figure 6:
Propagation
into carriage

Figure 7:
Mobile antenna
orientation

c) Mobile station are rather insensitive to antenna orientation

As explained in section 4.2, the difference between the CLs in the different antenna orientation is due to the directivity of the half-wave dipole which is used for CL measurements.

Conversely mobile station antennas (such as GSM, PCN, UMTS, etc.) are more sophisticated that the single dipole or monopole (which is illustrated in Figures 6 and 7). Their spatial response is different and much more "isotropic" than quarter-wave monopole and half-wave dipole antennas. Measurements performed with various mobile stations demonstrate that the received power is nearly independent of the antenna orientation. So, mobile station antennas behave as nearly isotropic antennas which pick up the strongest fiel component with a rather low gain (about −10 dB).

If the symbols CLr, CLp and CLo designate the coupling losses in the radial, parallel and orthogonal orientation respectively (whichever the probability level) and if the symbol CLmean corresponds to the mean coupling loss as define in the IEC 61194-4 standard, it is shown in section 4.2 that CLmean is generally about 4 dB higher than the lowest coupling loss. It results that, for practice, the following approximation can be made:

**CLmean = min (CLr, CLo, CLp) + 4**

where the "min" symbol designates the minimum of the values in brackets.

**This results means that calculating the link budget with the lowest coupling loss (CLr, CLp or CLo) instead of the average value (CLmean) is equivalent to a 4 dB decrease of the safety margin.**

### 3.3. Correction for longer distance

With "classical" transmitting antennas, the received power decreases as a function of the square of the distance d, i.e.:

$$\rightarrow P_{rec} \div \frac{1}{d^2}$$

This is a consequence of the "spherical symmetry" (the radiated energy is contained in a sphere of radius equal to d. With RCs, the radiated energy is contained in a cylinder of radius equal to d, hence a "cylindrical symmetry". Consequently, the received power decreases as a function of the distance d, i.e.:

$$\rightarrow P_{rec} \div \frac{1}{d}$$

The CL50% is specifie at 2 m of the RC according to the IEC 61196-4 standard. If it is required at another distance, the following correction should be applied:

$$\rightarrow CL50\%(d) = CL50\% + 10\log(\frac{d}{2})$$

For the CL95%, a longer distance involves a stronger influenc of scattered radiations and reflection on walls and ceiling, hence a fading increase. The following correction can be applied:

$$\rightarrow CL95\%(d) = CL95\% + 20\log(\frac{d}{2})$$

### 3.4. Penetration loss

For communications into vehicles, the link budget must take a penetration loss into account. This penetration loss is strongly influence by the frequency, the widow sizes, the glass type (single or double layer) and the possible presence of metal coating (for thermal insulation). For example, at 900 MHz, penetration loss may range from 2 or 3 dB for a single layer glass. It reaches 30 dB in the case of metal coated glasses.

### 3.5. Mobile antenna loss relative to dipole

The antennas used in mobile phones (such as GSM, PCN, UMTS, etc.) have a negative gain with respect to the half wave dipole normally used to measure the CLs. Their spatial response is however more “isotropic”. A 10 dB mobile antenna loss relative to half wave dipole seems a realistic value.

### 3.6. Safety margin

A 10 dB safety margin is recommended to account for:

- the differences between the standard conditions in which the CLs are measured and those actually met in a real tunnel environment;
- the various factors which may impair the RC performances.

As explained in section 3.2., a link budget based on a CL averaged over three antenna orientations provides a safety margin which is 4 dB superior to a budget calculated with the value measured in the best orientation.

# 4. COUPLING LOSS

## 4.1. Measurement procedures

The procedure to measure the CL is define  by an IEC 61196-4 standard. Two configu ations are permitted, i.e. : the "ground–level method" and the "free-space method". These two configu ations often give results that may be quite different. That is not surprising as it is well known that the environment affects the RC performances. As explained is this section, the ground–level configu ation is closer to the conditions actually found in tunnels.

In addition, the standard allows to specify either a CL for a "single orientation" (i.e. radial, orthogonal or parallel) or a mean value calculated with a specifi  formula. This issue is examined in section 4.2.

The fact that the IEC standard is not very restricting may be confusing, especially when the performances published in the manufacturer data sheets have to be compared. Some clarification  are provided here after to assist the radio engineer in making the most accurate link budgets.

### 4.1.1. Ground–level versus free-space method

The two configu ations are detailed in the annex B of the standard (§B1.1 and §B1.2) and are shown in Figures 8 and 9 respectively.

In the ground–level method, the RC is laid at 10 to 12 cm above a concrete ground. The centre of the antenna is positioned vertically at 2 m above the RC. The fiel  strength is recorded when moving the antenna along a path parallel to the RC.

In the free-space method, the RC is hung to non metallic posts at a height of 1.5 to 2 m. The antenna centre is at 2 m from the RC and at the same height. The fiel  strength is recorded when moving the antenna along a path parallel to the RC.

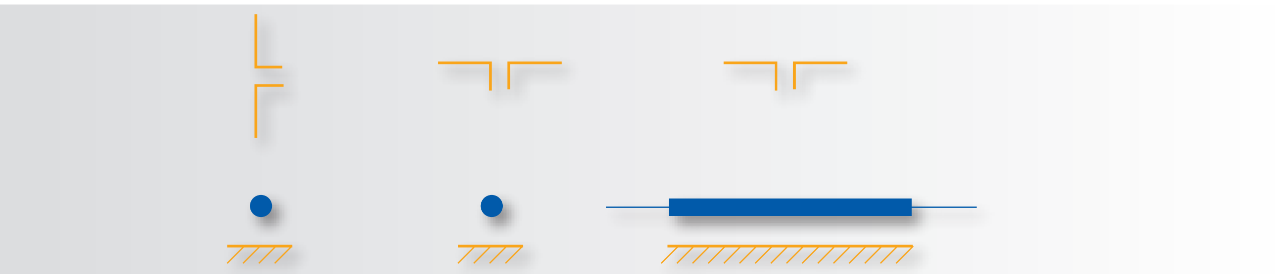


Figure 8:
RC and antenna positions with ground-level method

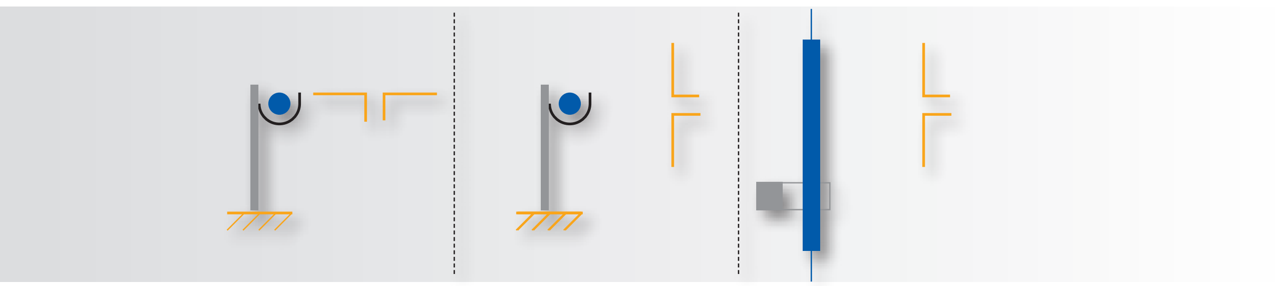


Figure 9:
RC and antenna positions with free-space method

The Figures 8 and 9 also defin  the three antenna orientations, i.e. :

- **Radial:** the dipole is orientated at right angle with respect to the RC and is in the same plane;
- **Orthogonal:** the dipole is at right angle with respect to the plane containing the RC;
- **Parallel:** the dipole is parallel to the RC.

Ground-level and free-space methods sometimes give rather different CL results; to explain these differences, coupled mode and radiated mode have to be treated separately.

**Coupled mode cables**

The difference between CLs with ground-level and free-space methods may be relatively important and sometimes exceed 10 dB. In general, the ground-level method gives lower CLs; this is not surprising as the surface close to the RC contributes to the coupled mode generation. In the free-space configu ation, the ground is at 2 m and is too far to efficient y promote the coupled mode.

It must be reminded that the radiated mode cables work in coupled mode below the transition frequency (which depends on the RC design). Consequently, the above remarks are also applicable to these RCs when they are used below their transition frequency.

**Radiated mode cables**

For the RCs working in radiated mode, CL differences of 2 or 3 dB between the two configu ations are usual but rarely exceed 6 or 7 dB. This difference may be either positive or negative, depending on RC design and frequency.

The CL differences are mainly due to the effect of the reflection on the ground surface. Indeed, in the ground-level configu ation, the reflection produced by the concrete surface located at 10 to 12 cm from the RC have a relatively important effect. The reflectio mechanism is shown in Figure 10 where only one single aperture A has been considered for simplicity. At any point P in the RC vicinity, the fiel strength is the vector addition of the fiel radiated by the aperture A (hereafter termed “direct wave”) and the one reflec ed at the point R by the concrete ground.

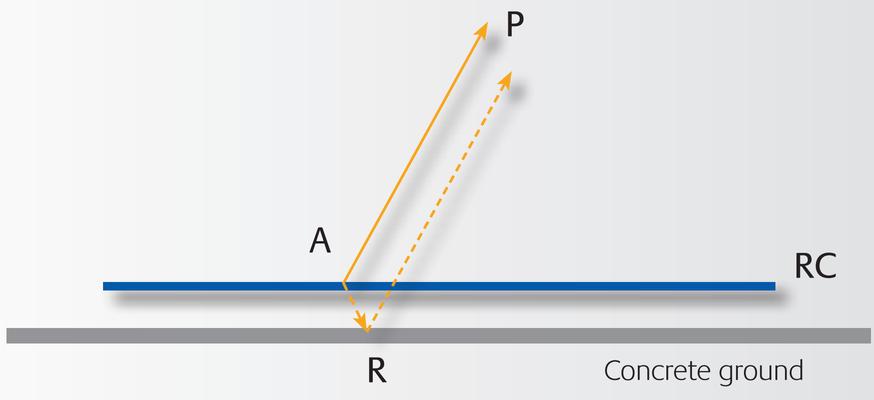



Figure 10: Reflectio mechanism with ground-level method

The magnitude of the resulting fiel will depend on:

- **the magnitude of the reflected signal:** this magnitude depends on surface conductivity. The reflectio coefficien may range between 0 (no reflection and 1 for a perfectly conductive surface.
- **the phase difference between the direct and the reflected waves:** the direct and reflec ed waves do not travel the same distance, hence a phase difference. Its value (in degrees) is given by the expression 360° x (AR + RP – AP)/$\lambda$ where $\lambda$ is the wavelength in the air.

In addition there is a possible phase shift at the reflectio point R. This phase shift depends on the direction of the electric fiel and on the electrical properties of the concrete surface. In the case of a perfectly conductive surface, there is no phase shift for the component of the electric fiel which is orientated at right angle with the concrete ground. Conversely, the component of the electric fiel parallel to the ground experiences a 180° phase shift.

Figure 11 shows how the reflection impact the CL. In this Figure, ***Ěd***, ***Ěr***, and ***Ě*** designate the electric fiel vector at the point P corresponding to, respectively, the direct wave, the reflec ed wave and the resultant field The left part of this Figure shows the case where the vectors corresponding to the direct wave ***Ěd*** and reflec ed wave ***Ěr*** are nearly in phase. The magnitude of their resultant ***Ě*** being higher than ***Ěd*** as the reflectio reinforces the direct wave, hence a CL decrease.

Conversely, the right part of Figure 11 shows the case where the vectors corresponding to the direct wave ***Ěd*** and reflec ed wave ***Ěr*** are nearly in opposition. The magnitude of their resultant ***Ě*** is lower than ***Ěd***, hence a CL increase.

Although it has been assumed, in Figure 11, that the reflectio coefficien was lower than 1 (the ***Ěr*** vector is shorter than ***Ěd***), it is obvious that the above conclusions apply whichever the magnitude of the reflec ed wave.

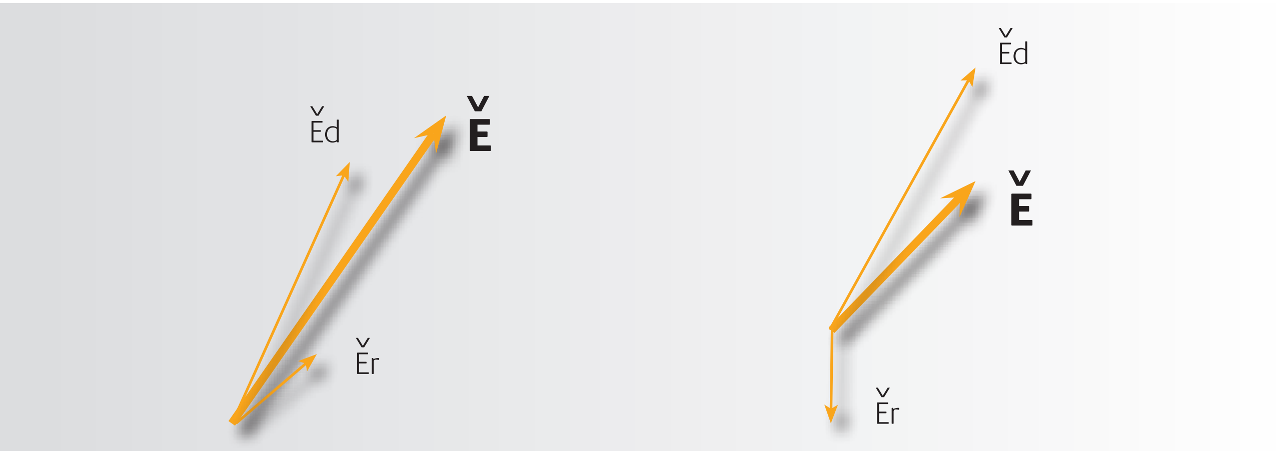



Figure 11: Vector addition of the direct and reflec ed waves when they are nearly in phase (on the left) and nearly in opposition (on the right).

With the wideband RCs, it is not easy to keep the direct and reflec ed waves in phase (or nearly in phase) in all the frequency bands as this parameter depends on $\lambda$.

In the most favourable case, i.e. when there is a total reflectio (reflectio coefficien = 1) in phase with the direct wave, the resultant ***Ě*** = 2 ***Ěd***, hence a 6 dB CL decrease.

Conversely, the worst case occurs where there is a total reflectio in opposition with the direct wave because the resulting fiel drops sharply, hence a severe CL increase. In practice however, the resulting fiel does not collapse completely and the CL increase should not exceed 20 dB.

Compared to a situation where there is no reflection  the ground-level configu ation may either produce a CL decrease of maximum 6 dB or an increase that should not exceed 20 dB.

In the free-space configu ation, there are also reflection  on the ground surface but their effect is much less important as illustrated in Figure 12. Of course, if the RC is at 2 m above the concrete ground, the reflection  can be seen as produced by an electrical image located at approximately[2] 4.5 m of the antenna. As the electromagnetic fiel  decreases with the inverse of the distance, the magnitude of the reflectio  is about 0.44 times (i.e. 2 m /4.5 m) the magnitude of direct wave when the reflectio  coefficien  is **equal to 1**. It results that, if the direct and reflec ed waves are in phase, the CL decrease[3] is about 3.2 dB. If they are in opposition, the CL increase does not exceed 5 dB.

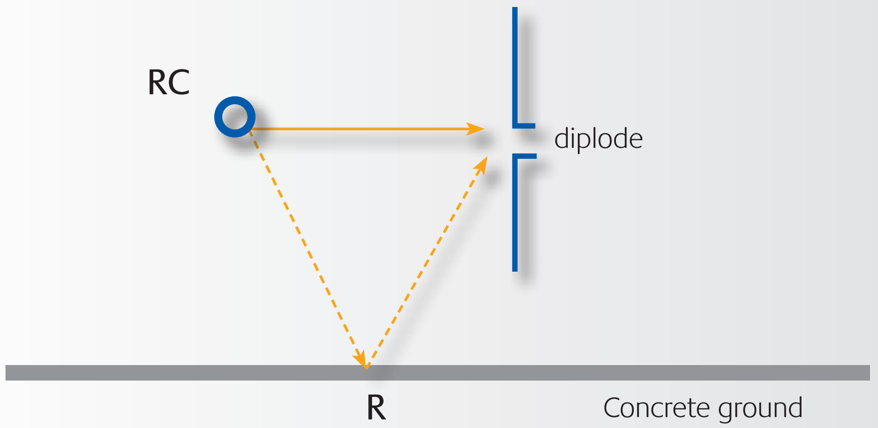



Figure 12: Reflectio mechanism with free-space method

If the reflectio  coefficien  is lower than 1, the magnitude of the reflectio  and the impact on the CLs is reduced accordingly.

It results that the impact of the reflection  are less important in the free-space configu ation than in the ground-level one where the direct and reflec ed waves travel nearly the same distance. This conclusion applies whichever the value of the reflectio  coefficient

### 4.1.2. Ground–level versus or-space method

In most applications, the RC is hung at short distance from a surface (ceiling or wall) producing reflection which may either improve or impair the CLs. It is obvious that the ground-level method is closer to the conditions actually met in practice. This is the reasons why the ground-level method seems the most sensible to refer to.

### 4.1.3. Eupen RMC Range

The Eupen RMC range is designed to derive benefi  from the reflectio  phenomenon, at least in most frequency bands allocated to mobile communications. This is achieved by choosing a launching angle that minimises the phase difference between direct and reflec ed waves.

All the Eupen RC data sheets specify the CLs (50 and 95% probability) measured in the ground-level configu ation. However, data sheets with the CLs measured in the free-space configu ation are also available for most Eupen RCs.

[2] According to Pythagora's theorem, (4_ + 2_)1/2 = 4.5 m
[3] 20 log (1 + 0.44) = 3.2 dB and 20 log (1 - 0,44) = 5 dB

## 4.2 Coupling loss and antenna orientations

### 4.2.1. CL definitions according to the standard

The IEC standard allows to specify the CL measured either in a single orientation (i.e. radial, orthogonal or parallel) or a mean CL calculated with a particular formula given hereafter. Figures 8 and 9 show the three orientations for the ground-level and free-space configu ations respectively.

Measurement results indicate that the CL difference between the worst (highest CL) and the best (lowest CL) orientations may exceed 10 and even 15 dB in some cases. The explanation of this effect is given in Figure 13 where it is assumed that a vertically polarised electromagnetic fiel propagates from the left to the right as indicated by the vector $\check{v}$. The three considered antenna orientations are and identifie by the letters a, b and c.

If the antenna arms are orientated horizontally and parallel to the direction of propagation (letter a), the response should be theoretically null because the main lobe of the radiation pattern is pointing in the vertical plane.

If the antenna arms are orientated horizontally and parallel to the direction of the magnetic fiel (letter b), the radiation pattern is pointing toward the source of the fiel but the response should be theoretically null because the arms are perpendicular to the electric field

The maximum received signal is obtained with the antenna arms orientated vertically (letter c). Indeed, the radiation pattern is pointing toward the source of the fiel and the antenna arms are parallel to the electric field

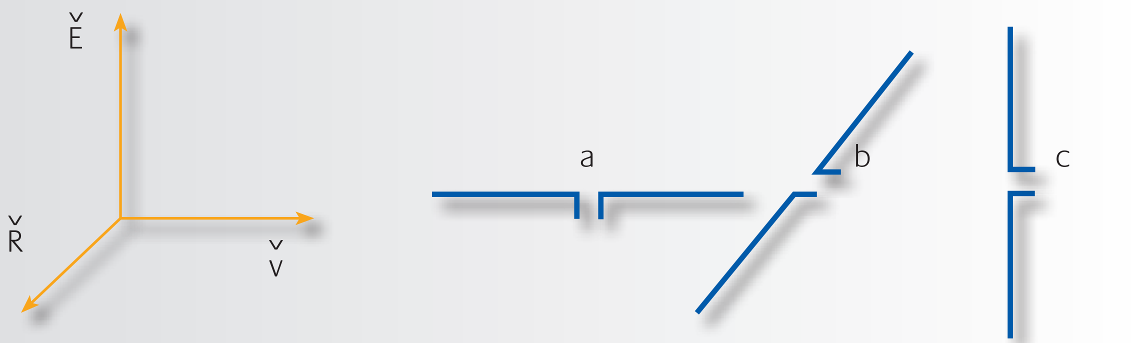



Figure 13:
Half-wave dipole response

The fact that the fiel produced by a RC is polarised explains the strong influenc of the antenna orientation on the CL.

As CL difference between orientations may exceed 10 and even 15 dB in the worst cases, correct understanding of the impact of this parameter is required for accurate link budget calculations and when the performances of RCs from different manufacturer have to be compared.

The IEC standard also define a mean CL calculated with the following formula:

$$CLmean = -10\log[\frac{1}{3}(10^{-CLr/10} + 10^{-CLo/10} + 10^{-CLp/10})]$$

This particular formula is different from the usual arithmetic and geometric averages. To understand its physical meaning, let's consider an RC feed with an input power equal to 1 mW (0 dBm). The term $10^{-CLr/10}$ in the above formula corresponds to the power (in mW) received by a dipole antenna orientated in the radial direction. Likewise, the terms $10^{-CLo/10}$ and $10^{-CLp/10}$ correspond to the power received by a dipole antenna orientated in the orthogonal and parallel directions respectively.

Consequently, the term $(10^{-CLr/10} + 10^{-CLo/10} + 10^{-CLp/10})/3$ is the sum of the power (in mW) received with the dipole orientated in the three different directions divided by 3, i.e. the received power averaged on the three orientations. It appears that the above formula gives in fact the CL with respect to the mean value of the power received in radial, vertical and orthogonal orientations.

To understand the implications of this definition let's consider the simple case where the electromagnetic fiel is perfectly polarised in one direction, for example the parallel one. This involves that only $CL_p$ has a fini e value while $CL_r$ and $CL_o = -\infty$.

As $10^{-\infty} = 0$ and as $-10\log[\frac{1}{3}(10^{-CLp/10})] = -10\log[\frac{1}{3}] - 10\log[10^{-CLp/10}]$

We obtain final y:

**CLmean = 4.8 + CLp**

In the actual situations however, the fiel is nearly never purely polarised in only one direction (i.e. there is no direction for which the received power is null). For instance, if CLr = 60 dB, CLo = 70 dB and CLp = 70 dB, we obtain CLmean = 64 dB. Other numerical examples confi m that the CLmean is generally about 4 dB higher than the lowest CL. In conclusion, for practice, the following approximation can be made:

**CLmean ≅ min (CLr, CLo, CLp) + 4**

where the "min" symbol designates the minimum of the 3 values in brackets.

Although, the standard imposes to specify the antenna orientation, this information is lacking in most manufacturer data sheets. Consequently, RC performances comparisons are sometimes difficul as the given CL could either be a mean value or measured in a single unknown orientation.

### 4.2.2. Antenna orientation and link budget

As stated above, the CL in the "worst orientation" may be 10 to 15 dB higher than in the "best orientation". This is mainly due to the fact that the measuring antenna is a half-wave dipole which features directivity. Indeed, the radiation pattern is the typical eight figu e with a null response in median plane. Consequently, the CL depends on the direction of propagation of the wave radiated by the RC and on the orientation of the electrical fiel as shown in Figure 13.

In practice however, the antenna orientation is nearly never perfectly radial or parallel or orthogonal with respect to the RC but rather a combination of these three possibilities. Indeed, the mobile antenna is often down tilted and is rarely in an RC plane.

This remark also applies with handheld equipments. Moreover, their antenna is, generally, much less directive than a dipole. It means that their radiation pattern is more "isotropic", resulting in a decreased CL sensitivity to the antenna orientation. Consequently, the CLmean is recommended for link budget calculation in the case of communication with mobile phones. In addition, it must also be reminded that mobile phone antennas have gain substantially lower than the half-wave dipole.

For all these reasons, the Eupen RMC data sheets specify the CL50%-mean and CL95%-mean. Detailed measurement reports with the CLs for the three orientations are available on request.

# 5. RC PERFORMANCES OPTIMISATION

## 5.1. RC positioning

The mobile antenna position and orientation are important parameters for performances optimisation of radio communications in confine spaces. Mobile antenna mounted on the vehicle roof and hand-held equipments on-board train are the main cases encountered in practice. They are detailed hereafter.

### 5.1.1. Mobile antenna mounted on the vehicle roof

Figure 14 shows two typical examples with the mobile antenna installed on the vehicle roof (train, car, ...). It is generally a quarter wave monopole or a whip vertically oriented or down tilted.

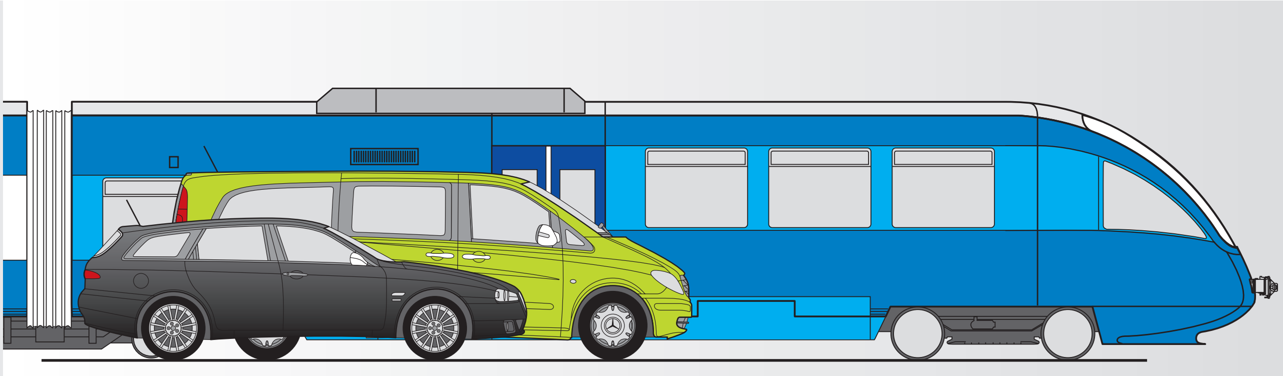


Figure 14:
Mobile antenna installed on the vehicle roof

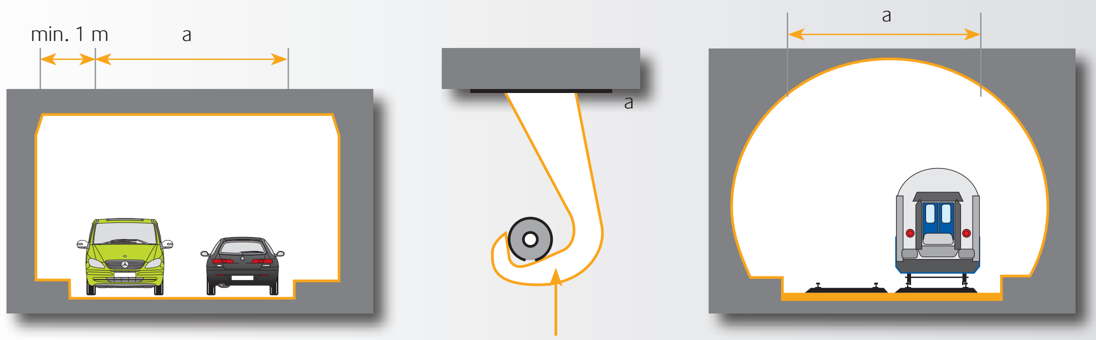



Figure 15:
RC positions if the mobile antenna is installed on the vehicle roof

As the electric fiel radiated by the RC has a strong radial component, the best coupling is obtained with the RC hung from the tunnel ceiling and preferably near the centre position or at least 1 m away from the side walls as shown in Figure 15.

The lowest CL and fiel strength fluctuation are obtained with the apertures located on the mobile side. The aperture side is marked on the RC jacket. Figure 12 shows the RC and aperture positioning recommendations if the mobile antenna is installed on the vehicle roof.

### 5.1.2. Hand-held mobile equipment on board train

It is obvious that the orientation of a hand-held equipment antenna is nearly never vertical in normal use as shown in Figure 16.

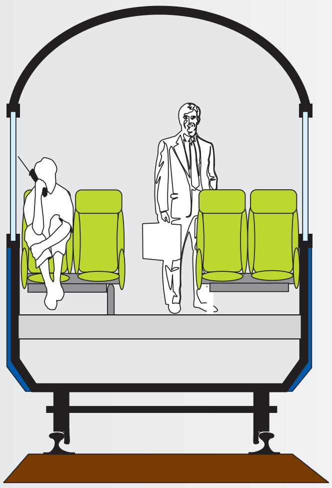


Figure 16:
Hand-held equipment orientation

The radio waves enters carriages only through the windows with a penetration loss which depends on glass material (number of layers, metal coating,...) and window sizes.

In all cases, the best coupling is obtained with the RC hung along a wall as shown in Figure 17 (hand-held on the RC side and hand-held on the opposite side). It is recommended to hang the RC approximately at the same height as the upper edge of the carriage windows as shown in these figu es.

Again, the lowest CL and fiel  strength fluctuation  are obtained with the apertures located on mobile side.

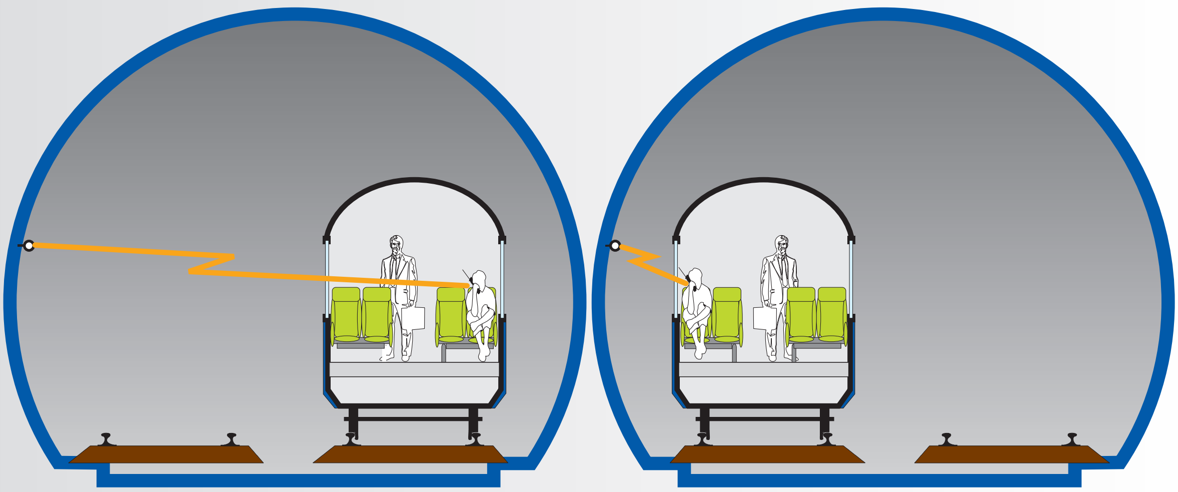


Figure 17:
Recommended RC positions for communication with passengers on board train

## 5.2. Multi-cable system

In some cases, two parallel RCs are used in the same tube to improve the system reliability. The diagram in the upper left corner of Figure 18 shows a configu ation where two nearby RCs are fed with the same RF source. This solution will give rise to large fiel strength fluctuation due to the constructive and destructive interferences between the signals radiated by the two RCs. Of course, the signal at frequency f1 and f3 are simultaneously radiated by both RC1 and RC2. Hence, such a configu ation **must absolutely be avoided.**

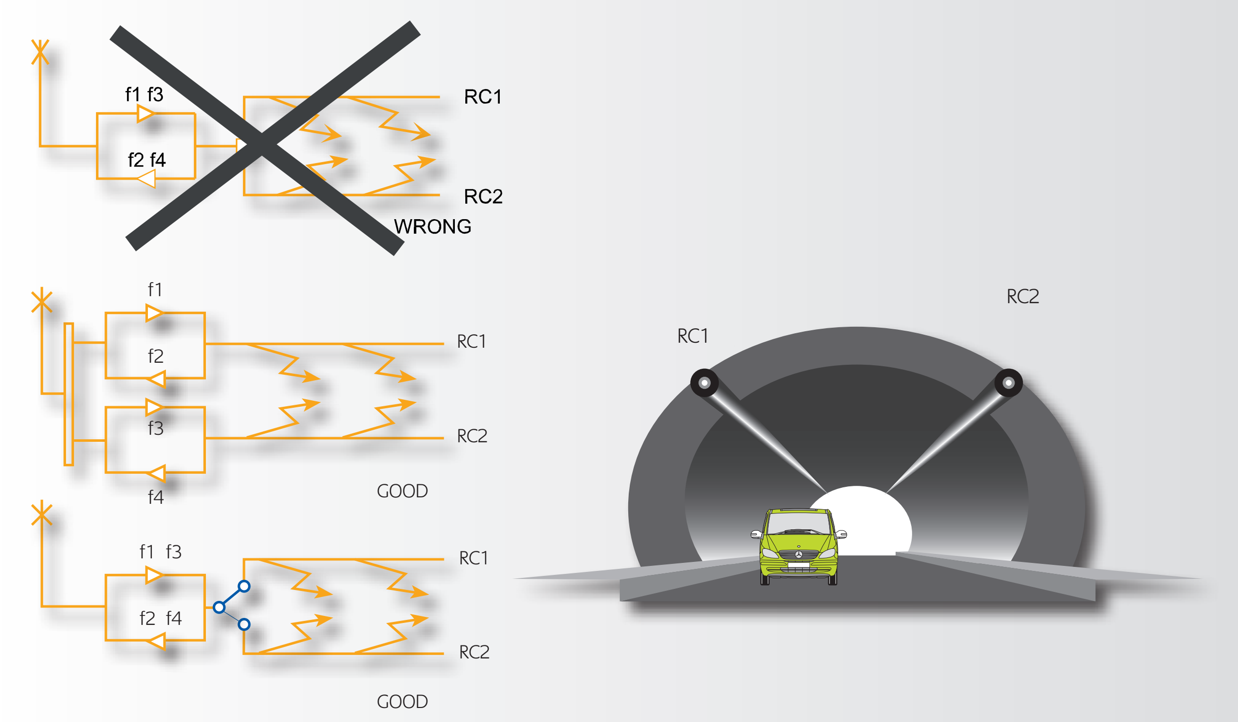



Figure 18:
Multi-cable system

Where the specification impose a second RC, one of the following solutions can be used to meet the reliability requirements without loosing the benefi of low fiel strength fluctuations

### ➔ Feeding the 2 RCs with different carrier frequencies

The 2 RCs are fed with different carrier frequency sets as shown in the second diagram of Figure 18. Thus $RC_1$ radiates $f_1$ only and $RC_2$ radiates $f_3$ only. The same principle applies for the up-link with $f_2$ and $f_4$.

### ➔ Use of only 1 RC at a time

Only $RC_1$ (main link) is active in normal operation conditions as shown in the third diagram of Figure 18. $RC_2$ (spare link) is activated in case of $RC_1$ link failure.

## 5.3.Resonant frequencies

Due to the fact that Radiating Mode Cables are based on a slot design with evenly spaced, repeating slots, it is a physical rule that this will lead to Resonances.

On Eupen's EUCARAY® Radiating Cables, it results in **clearly identified Resonant Frequencies**. In most cases, the Resonant Frequencies occur in **non-used Bands of the Radio Spectrum**, and the even multiples are actually suppressed once the Cable has been installed. In addition, their magnitude generally decreases the higher the order.

It is good practice to verify that the Resonant Frequencies of a chosen EUCARAY® Radiating Cable do not appear in the required and used RF-Band. However, should a Resonant Frequency be found in the RF-Band to be used, it does not necessarily result in a Radiating Cable being unsuitable. On Eupen EUCARAY® Radiating Cable, Resonant Frequencies occupy only about 1 MHz of bandwidth, so that the transmission at frequencies located before and after a particular Resonant Frequency is not impacted. Further, the result at the said Resonant Frequency will typically be a slight increase in the Longitudinal Loss on the Downlink and a slightly raised VSWR in the Uplink. In both cases, the impact on the working of an RF System should be quite marginal. To compare, one should also bear in mind that a well-matched Antenna will have a typical VSWR of 1.5:1.

### Resonant Frequencies versus Stop Bands

Resonant Frequencies on Eupen EUCARAY® Radiating Cables **should not** be compared to Stop Bands of other Manufacturers Cables. Such Stop Bands, or unauthorised Frequencies, usually occupy a much wider bandwidth, and the high level of reflected signal – with VSWR typically >> 10:1 – makes it **impossible to use** those Cables within the given frequency band.

The illustrations 1 & 2 below show the actual impact the Resonant Frequencies have on the VSWR and the Attenuation of one Eupen RMC-type Radiating Cable.(*)

The illustrations 3 & 4 show, at same scale, the impact of a Stop Band on a competitor cable.(*)

(*) Example with 1-5/8" size, broadband radiating cables.

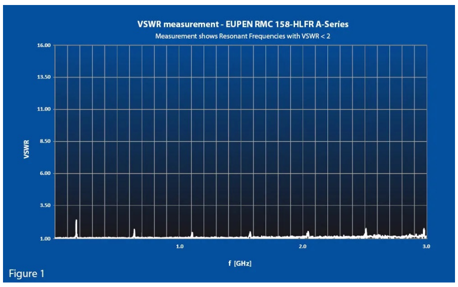
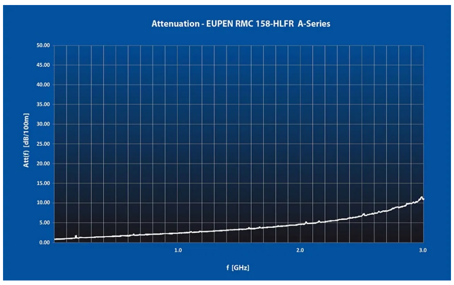


Figure 1



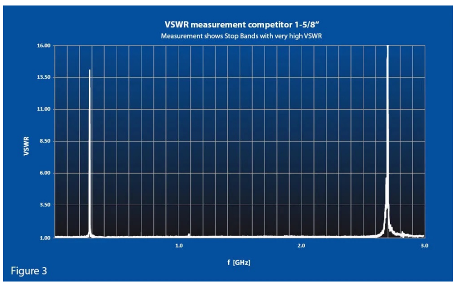
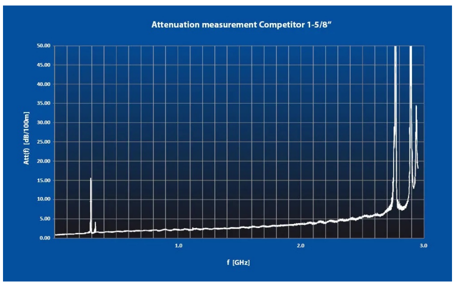
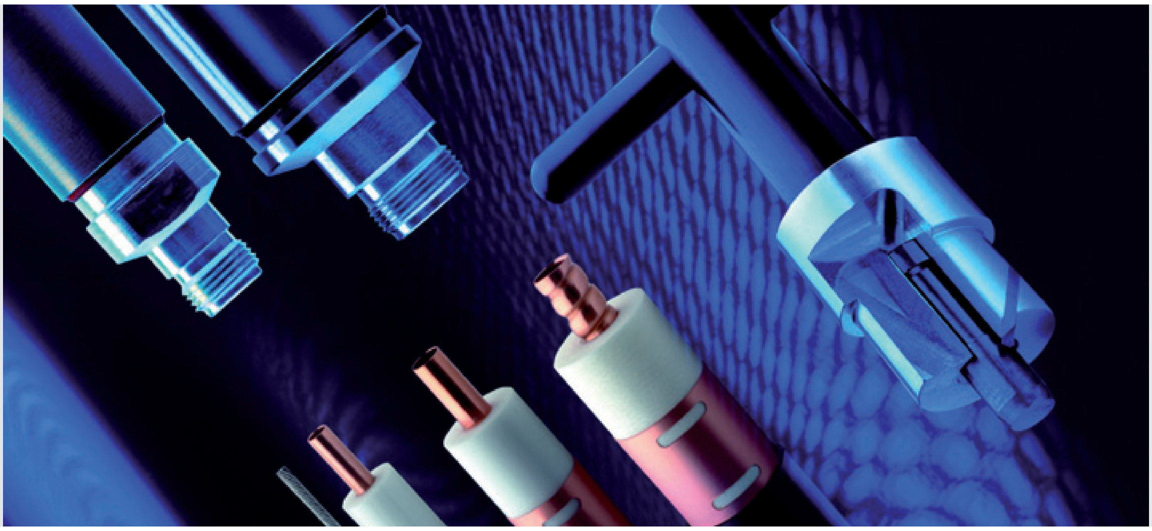



Figure 3



# EUPEN CABLE

## Your reliable Partner for RF Communications



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