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Use of mobile radio on the railways - Antennas

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Summary

When using antennas in railway mobile radio service, there are strict requirements to be met in terms of the choice of suitable antennas, location, mechanical mounting, electrical connection and environmental influences. Only by taking proper account of all of the points can the satisfactory functioning of the installation be garanteed.

1 - Introduction

This leaflet gives an overview of the current use of antennas in railway mobile radio service and the experience gained. It identifies the most important general aspects to be taken into account in manufacturing antenna systems and deals with the measures to be adopted to enable their use on electrified lines. It further defines the main characteristics of the most commonly used antennas.

2 - Classification of antennas

There are numerous different types of antennas, each giving advantages and disadvantages, depending on their intended use. An antenna represents the impedance matching zone between a guided wave and a wave radiated in the free field. All types of antennas in use today originate from the concept of an idealised continuous transition. Depending on the application (450 MHz PMR, 900 MHz GSM), specific antennas have evolved from the basic configurations.

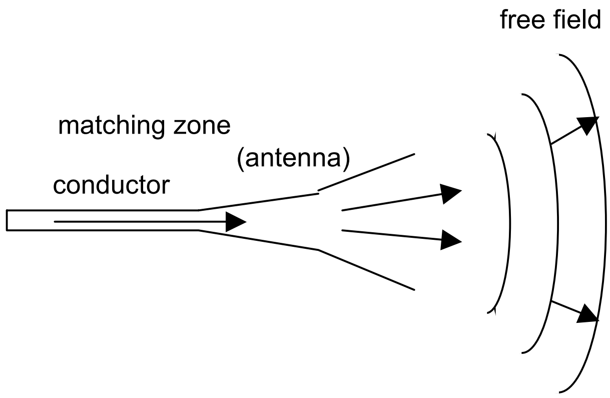
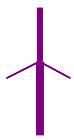
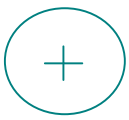
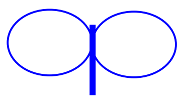
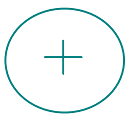
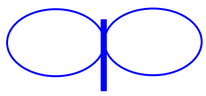
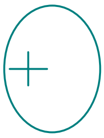
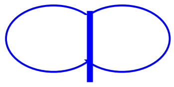
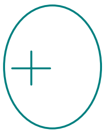
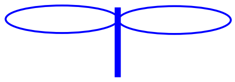
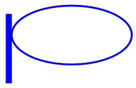
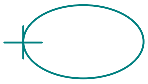
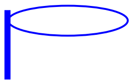
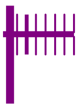
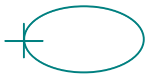
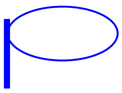
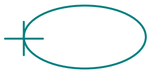
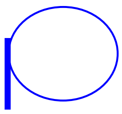


Fig. 1 - Principle of an antenna

Antennas are classified in accordance with their structural characteristics, producing the following categories for those antennas most frequently used for railway mobile radio:

NB : position of the mast with regard to the antenna diagram is for indication only.

Type of antenna	Horizontal diagram	Vertical diagram
 λ/4 rod		
λ/2 rod		

Type of antenna	Horizontal diagram	Vertical diagram
 Dipole		
 Dipole array		
 Dipole with corner reflector		
 Dipole field		
 Yagi antenna		
 LogPer antenna		

2.1 - Ground plane and rod antenna

The ground plane and rod antenna is a co-axial system development with a split conductor.

The thinner the structural components of an antenna, the more selective the originally wide-band transformation system. This also means that structural impedance-matching will be more difficult in a desired frequency range.

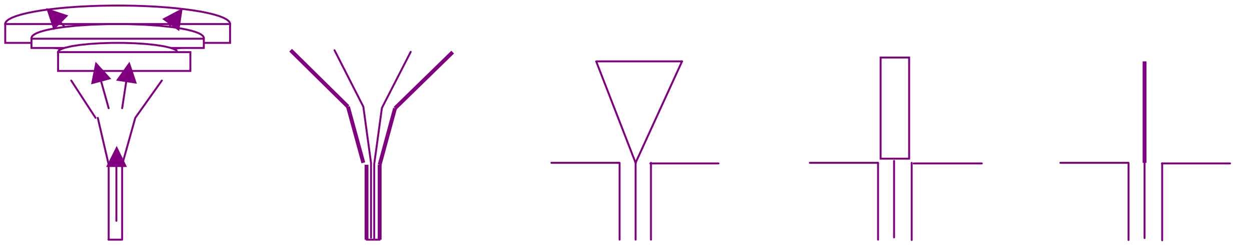


Fig. 2 - Principle of a rod antenna

This type of omnidirectional antenna has little or no directivity. Radiation is regular to all sides and the antenna diagram is circular. The gain obtained is generally small.

2.1.1 - Dipole antennas

Dipole antennas are a development from a symmetrical conductor system with a split conductor.

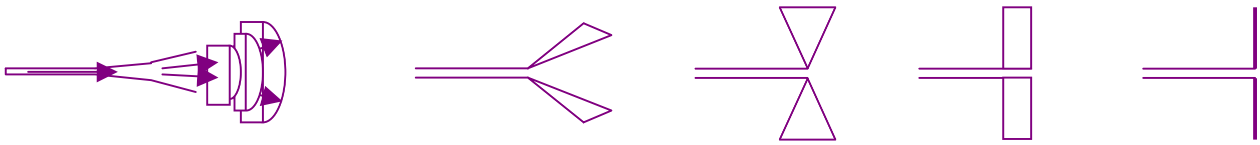


Fig. 3 - Principle of a dipole

Dipoles are open-ended rod antennas of virtually symmetrical construction with lengths of 1/2 or 1/4 wavelength.

2.1.2 - Dipole with corner reflector

Dipole with two parallel reflectors flanking the dipole on two sides.

2.1.3 - In-line dipoles

Several dipoles arranged in a line.

2.1.4 - Yagi antenna

Antenna comprising a simple dipole or folded dipole with an indirectly fed reflector and one or more indirectly fed directors.

2.1.5 - Log-periodic antenna

Log-periodic antennas comprise single dipoles, the length and spacing of which are selected such that a wide-band antenna is produced. A single antenna can cover frequency ranges of several 100 MHz.

2.1.6 - Antenna fields

Antennas comprising several individual antennas for the purpose of obtaining the desired amplification and directivity.

2.2 - Basic rod antenna

Rod antennas used in portable equipment in particular.

2.2.1 - $\lambda/4$ or $\lambda/2$ antenna

Comprises a rod radiator with 1/4 - 1/2 wavelength, the mass of the unit or vehicle acting as counterpoise (or ground plane).

2.2.2 - $\lambda/4$ or $\lambda/2$ folding antenna

This is also a rod antenna, the radiator of which comprises two closely spaced parallel conductors connected to one another at the ends.

2.2.3 - $\lambda/4$ or $\lambda/2$ antenna with counterpoise

Rod antenna comprising a single radiator with 1/4 or 1/2 wavelength, the counterpoise of which comprises a number of conductors arranged in a virtually perpendicular plane to the radiator.

2.2.4 - $\lambda/4$ or $\lambda/2$ folding antenna with counterpoise

Same antenna as described in point 2.2.3, the radiator of which comprises two closely spaced parallel conductors connected to one another at the ends.

2.2.5 - Cylindrical antenna

A single radiator with very short wavelength (l < 1/10 wavelength) and a large diameter in the form of a cylinder open at one end, which at the same time acts as a suppressor.

2.3 - Radiating cables

In addition to antennas, radiating cables in particular are often used for radio systems in tunnels (railway tunnels, metro lines). They consist of coaxial cables, the shielding of which has regularly spaced openings, from which signals are continuously sent out along the entire length of the cable. Specifications for these cables are provided by the respective manufacturers in respect of their longitudinal and coupler attenuation and it is therefore possible to calculate radiation and attainable coverage, as in the case of normal antennas. Depending on the frequency range, distances of up to 1 000 m can be covered using leakage cables. Depending on services, the mounting position can be optimised (high in case of roof antennas, at window height for GSM without repeaters inside vehicles).

Diagram showing radiating cable levels

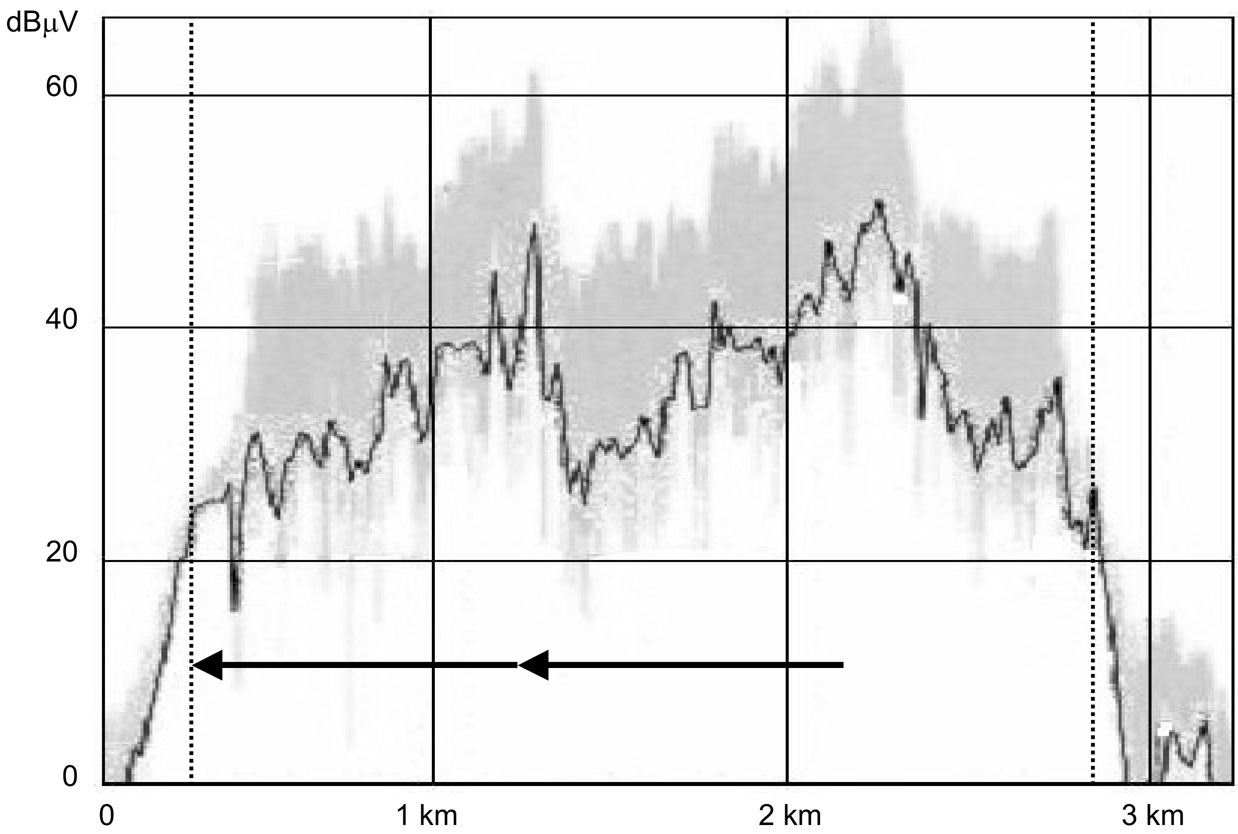


Fig. 4 - 2,3 km tunnel, with down-link coverage in two 1 000 m sections by a radiating cable

Note the heavy signal distortion caused by the tunnel structure and the fading produced as a result of strong reflections. The diagram contains the measured actual signal and the values for 95% local probability.

Appendix A - page 13 informs about the use of antennas according to antenna type and railway domain of application

3 - Use in fixed stations

The construction of an antenna including its counterpoise is of great importance in mobile radio. It determines the power radiated by the transmitter and the sensitivity of the receiver and consequently guarantees, to a large extent, the success of the equipment. Location, directivity and geometric dimensions of the antenna can be selected within a wide range, so that, by making the appropriate choice, a variety of requirements can be met. In addition to their electrical characteristics, it is important to consider in particular the mechanical design of antennas for vehicles and portable devices.

In order to prevent losses, care must be taken to ensure that the antennas are matched to the feeder line at the final stage of the transmitter and at the receiver input respectively. A standing wave ratio of 2,5 should not be exceeded. All feeder lines should be kept as short as possible in order to keep attenuation losses small, particularly since low-attenuation cables can be costly.

Antennas in fixed stations should be selected such that the intended coverage is achieved. Mounting height, antenna gain, directivity, power range and mechanical strength should be matched to the corresponding system requirements and ambient conditions. If coverage is to be along a railway line, unidirectional antennas should be used rather than omnidirectional systems.

Wherever possible, antennas which cover a whole band (450 MHz PMR, 900 MHz GSM/GSM-R) should be used (LogPer antenna, wide-band dipole). If the gain and directivity requirements are high, antenna arrays should be used, taking care not to exceed of the maximum effective radiated power ERP allowed by the regulators. Normally, the antenna supplier can also provide calculated gain and directivity data. For every installation, the details given under point 3.5 - page 9 concerning cable attenuation shall be taken into account. As a rule, specific antenna systems are associated with radio services such as PMR or GSM, as specified by the radio system supplier. It should be noted that, as a general rule, this concerns antennas for civil applications, which may not comply with the requirements of a railway (earthing, strength).

3.1 - General considerations for construction

Antennas are exposed to a variety of environmental influences (climate, wind, ice, vibrations), and must be mechanically dimensioned accordingly. In addition, depending on their location, they must be secured such that people and vehicles are not endangered in the event of a mechanical failure. The structural design should ensure easy access.

3.2 - Overvoltage protection and earthing

Any antenna located in the vicinity of overhead lines or other live conductors must be earthed and protected against overvoltage with appropriate devices (dischargers, earthing concepts). The earthing concepts must be compatible with local specifications and installations.

3.3 - Mechanical strength (icing/wind load/pressure waves in tunnels)

The antenna, including its mounting unit, must be strong enough to withstand the climatic influences likely to be encountered. In the open air, squalls of more than 160 km/h are possible; in tunnels, short-duration wind velocities of up to 60 km/h are produced as a result of passing trains. In the open air, loads can be produced in the winter as a result of wet snow and ice, attaining several times the weight of the antenna. It is particularly important for an antenna to continue functioning under such increased demands, since natural phenomena of this kind normally contribute to producing accidents or operating failures.

3.4 - Influences on antennas in tunnels

If antennas are used in tunnels, their behaviour is heavily dependent on their location (against the wall, in the crown of the tunnel, radiating in from the portal). Ideally they should always be located in the crown. But this can have practical disadvantages because of the proximity to catenary on electrified lines or heat from diesel exhaust. Antennas mounted laterally are screened to a much greater extent by passing trains. When the tunnel is occupied, periodic signal losses linked to train length can be observed. In addition, shadowing by the vehicles behind the locomotive has a significant effect. Serious consideration must be given to shadowing and all its influences at the planning stage, since radio coverage must be guaranteed, particularly for railway traffic in tunnels. Consideration of attainable coverage should therefore always be based on an occupied tunnel, with at least one train per track.

3.5 - Cable attenuation

It is essential that cable attenuation is as low as possible in the transmission and receiver paths. Low cable attenuation should be achieved primarily by using short cable lengths, and only as a second resort by using low-attenuation cables, which are generally very costly. A well-dimensioned cable system is almost always cheaper than an increase in transmission power or the use of pre-amplifiers.

4 - Use on vehicles

Short rod antennas with protective housing made of synthetic material are generally used on vehicles. For safety reasons, these are antennas with galvanic earthing and metallically conducting flanges bolted to the vehicle roof or ground-plane sheet. In order to keep the number of antennas on a vehicle roof down to a minimum, antennas that can cover several frequency bands at the same time should be used (410 - 470 MHz, dual band antennas for GSM 900/DCS 1 800 MHz, combined antennas for GSM/GPS). In order to prevent mutual interference between radio services (Intermodulation, wide-band noise), it is important to provide sufficient spacing between individual antennas.

4.1 - General considerations concerning siting and mounting

Since a vehicle roof is not an ideal surface for effective radiation from an antenna, it is essential to ensure that the antenna's radiation diagram does not deteriorate even further as a result of the antenna being mounted unsuitably close to other objects, such as the pantograph, brake resistors or high-voltage lines. Above all, care should be taken that a vehicle-mounted antenna is not shielded by other objects. Unsuitable mounting can cause major additional signal attenuation, which has to be compensated through costly measures applied to the fixed installation.

4.2 - Overvoltage protection and earthing

Every precaution shall be taken in order to prevent endangering people or systems inside a vehicle as a result of contact between the antenna and the overhead lines[1]. As a general rule, this is done by using antennas with galvanic earthing on vehicles, albeit with exceptions[2].

The galvanic earth connection must be at the very base of the antenna. In some countries, only vehicle-mounted antennas that have been approved by the responsible railway regulatory authority or railway company may therefore be used.

NB : Ungrounded antennas such as rod antennas and magnetic base antennas may not be used.

If, for technical reasons, a radio unit must be decoupled from the body of the vehicle, this decoupling should be achieved on the feeder side via a dc - dc converter, and not via the cable of the antenna.

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1. Appendix B is an example of Technical Specifications for cab radio antennas for SNCF rolling stock.
2. One alternative is to have the antenna galvanically separated from the radio. This could be done by converting the RF-signal from the antenna and transmitting it via a fibre optical cable into the train and then do the reverse converting before entering the radio. This solution requires an active electronic device in the antenna which needs to have a power supply. The protection (galvanic separation) of the power supply can be obtained by the use of a properly designed "separation transformer" placed in an earthed box inside the roof. Such a solution (patent pending) is in use for a satellite tracking antenna on board some Swedish high speed trains.

4.3 - Counterpoise

The roof surface of modern vehicles is often made of synthetic material and in order to prevent this having the effect of producing an even poorer radiation diagram (already seriously affected by obstructing superstructures on the vehicle roof), all antennas should be mounted on adequately dimensioned metal ground planes (sheets).

4.4 - Influences in the near field

A vehicle roof carries a variety of objects that can seriously change the omnidirectional range of a roof antenna (pantograph, brake resistors, alarm whistles, air conditioning units, switches, etc.). A typical diagram based on measurements performed by CFF is given below. Up to 60 dB attenuation can be produced. Particular care should be taken to ensure that as few obstructing objects as possible are located along the longitudinal axis of the vehicle.

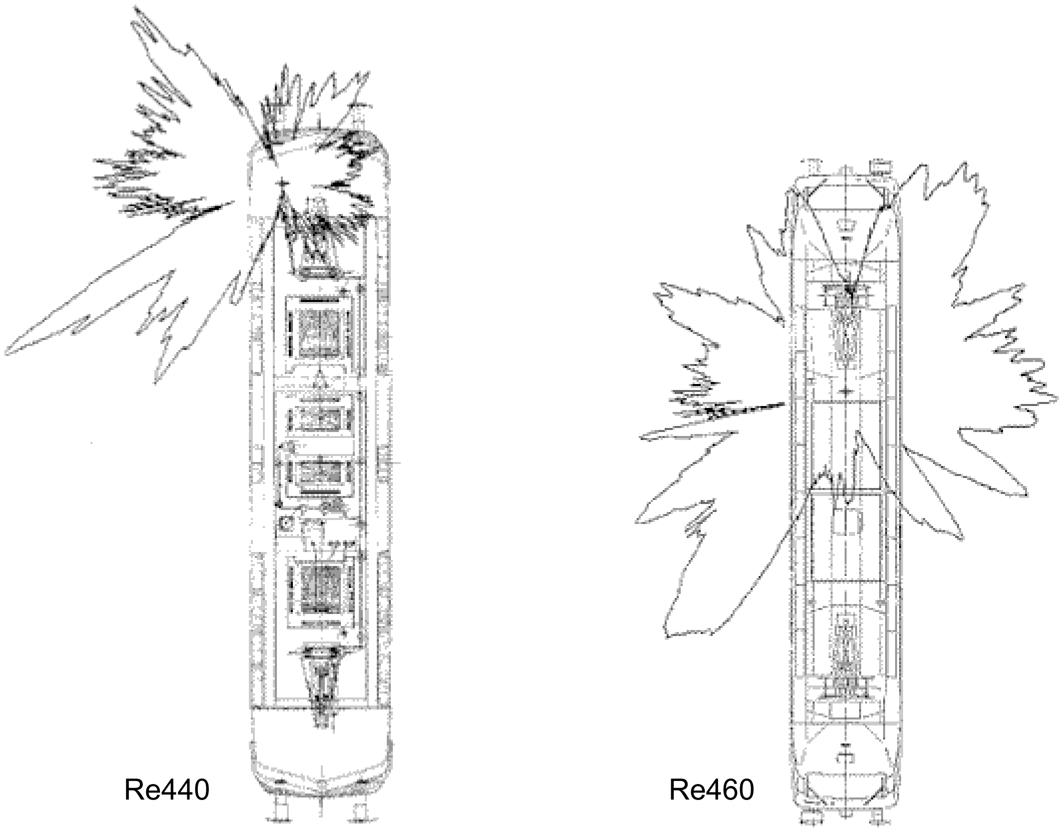

Fig. 5 - Examples of measured horizontal diagrams for vehicle-mounted antennas

4.5 - Cable attenuation

It is imperative to ensure that cable attenuation is kept to a minimum on the transmitter and receiver paths. Since, in contrast to a fixed station, a low-attenuation and therefore thick antenna cable cannot be placed (bending radii), the overall length should be kept as short as possible. In addition, care should be taken to ensure that connectors are correctly mounted in accordance with the supplier's specifications.

5 - Use in portable devices

For practical reasons, rod antennas are used in portable devices. These produce no noteworthy gain, but have the benefit of not obstructing in operation. Because the receivers generally have very sensitive input stages, it is still possible to continue up to the sensitivity limit set by ambient noise levels.

5.1 - Methods of carrying / body attenuation

Handsets are generally carried in a body strap. Because, as a result, the antenna is no longer in the free field, large-scale signal attenuation is to be expected (with $\lambda/4$ antennas up to 12 dB, with $\lambda/2$ antennas up to 4 dB). In addition, omnidirectional characteristics are no longer possible.

5.2 - Typical ambient losses

In and around railway vehicles, field patterns are attenuated to a certain degree owing to the presence of large metallic surfaces. The vehicle itself represents a shielded space. Since, for climatic reasons, the windows are metallically coated, 20 - 35 dB attenuation of signals between the interior and the exterior is to be expected. Outside, in the immediate vicinity of the vehicle, signals are attenuated by approx. 12 dB compared with a roof antenna. If, for shunting purposes, it is necessary to work in the kneeling position between vehicles, attenuation in relation to a roof antenna can be expected to be up to 35 dB.

Position	**Loss** (dB)	**Losses accumulated** (dB)
Roof-mounted antenna (reference)	0	0
Roof - Ground	-11	-11
Antenna losses through the body	-7	-18
Person turning	-4	-22
Lateral masking by vehicle	-6	-28
Polarisation of antenna	-3	-31
Kneeling for vehicle coupling	-4	-35
Typical total attenuation		**-35**

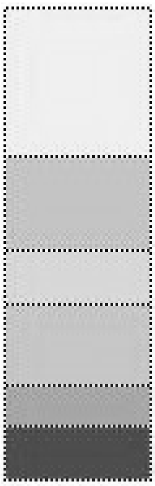

Fig. 6 - Influence of position on ambient attenuation

Appendix A - Antenna applications on railways according to antenna type

A.1 - PMR 450 MHz

A.1.1 - Dipole antenna with corner reflector, usually called a 9 dB dihedral, used for the limits of radio block sections. The rear lobe is very short.

A.1.2 - 3, 6, 9, and 12 dB Yagi antennas. Used for linear radio coverage of open lines. The higher the gain, the more directive is the antenna. 3, 6 and 9 dB Yagi antennas are used for lines with large numbers of curves, while 12 db Yagi antennas are used for straight lines. Their rear lobe is very short, which makes them well-suited for use at the limits of radio block sections. They may be coupled back to back on open lines in order to cover track renewal areas or high points. 12 dB Yagi antennas are also used for radio coverage in tunnels.

A.1.3 - Log-periodic antennas are small and have a very short rear lobe. they are used for radio coverage in tunnels with gauge restrictions and for short radio block section switching areas.

A.1.4 - Antennas with circular polarisation are exclusively used in tunnels. Their large reflector size (700 mm x 700 mm) makes them unsuitable for use in tunnels with gauge restrictions.

A.1.5 - Dipole and omnidirectional (basic rod) antennas are mainly used for local radio coverage in stations and marshalling yards.

A.1.6 - $\lambda/4$ or $\lambda/2$ rod antennas are mainly use on rolling stock.

A.2 - GSM 900 MHz

A.2.1 - Dipole field antennas with 15 to 17 dB gain are used for radio coverage on the open line. Two antennas can be coupled back to back and the coverage can be modified by tilting the antennas in the vertical plane.

A.2.2 - Bi-band helix antennas with circular polarisation and 14 dB gain are used in tunnels.

A.2.3 - Bi-directional, bi-band wall antennas with 6 dB gain are used to provide coverage in uncovered station areas.

A.2.4 - Omnidirectional ceiling antennas with 2 dB gain are used to provide coverage in uncovered station areas.

Appendix B - Technical specifications for train radio antennas for SNCF rolling stock

To protect staff in the event of a direct contact between a vehicle-mounted antenna and the high-voltage overhead lines, the radiating rod of the antenna must be able to conduct the short-circuit currents defined in the table below so that the downstream circuit-breaker can function properly.

Evacuation of short-circuit currents and behaviour before breakdown	
25 kV 50 Hz AC (standard NF EN 50388)	**1,5 kV DC (standard NF EN 50123)**
31,5 for a half period (10 ms)	70 kA for 5 ms
15 kA for 100 ms	40 kA for 100 ms

During the short circuit (time taken for circuit-breaker to react) the voltage at the antenna connector must not exceed the values-indicated in the table below:

Short circuit voltage over a short period	
25 kV 50 Hz AC (standard NF EN 50388)	**1,5 kV DC (standard NF EN 50123)**
Maximum voltage at the connector: 60 V	Maximum voltage at the connector: 48 V

Warning

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