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Antennas for Automobiles

Niels Koch

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1. Introduction

In recent years, we spent more and more time in our cars. So it became obvious to implement Car Entertainment Systems into the car for comfort and driver information. Car entertainment began with AM-reception on short wave bands. FM-tuners on VHF bands followed soon, with stereo sound, cassette players and CD-players to entertain passengers. Today we know a number of different analog- and digital broadcasting systems, such as DAB, DMB, DRM, DVB, as well as satellite broadcasting systems such as SDARS.

For driver information, modern navigation systems not only help to find the most efficient route, but also give an overview of traffic situation. Car-to-Car Communication and Car-to-Infrastructure Communication is currently one of the most popular field of researches for efficient car information systems.

All of these systems have in common that they are wireless systems, hence a number of antennas must be used satisfying all different services in different frequency bands. In modern cars we find up to 24 antennas placed on the vehicle and inside the vehicle. In the next years the number will even rise.

This Chapter is structured into different subsections. At first we set the requirements for vehicular antennas. Then we search for locations where to place the antenna for optimal reception and for which service and wireless system the best antenna technology is selected. All this is fundamentally supported by best-practice examples, including how to beat fading effects.

2. Requirements for vehicular antennas

In order to have a good reception in a vehicle, some prerequisites must be fulfilled.

First of all, and this seems very obvious, the antenna must receive from any direction around the car. If this requirement cannot be satisfied with one antenna only, then an antenna array (two or more antennas) shall be considered.

In general, an antenna shall be as high over ground on the vehicle as possible. The higher the antenna is placed over ground, the better it can receive and transmit.

Then the antenna must be integrated into the car easily. The distance to the receiver shall be not too far so that received signals are not extra attenuated before they are used. The surrounding of the antenna may influence the antenna performance severely. Hence the materials and distances around the antenna must be considered. As a rule of thumb, a box of 3 times antenna size around the antenna shall be unobstructed. That means for VHF-antennas with 75 cm length, this requirement can never be fulfilled on regular cars, but can be easily achieved with Telephone or GPS-antennas above 1 GHz.

The engine generates spurious noise which can disturb reception, therefore the antenna shall be placed as far away from the engine as possible, but taking all other requirements mentioned before into account. So in total there will be a trade-off between height over ground, omnidirectional reception and reducing spurious emissions influences.

Sometimes the polarization of the antenna is of some importance, as some signals are transmitted specially polarized, e.g. SDARS is left hand circular polarized.

Summary of requirements for ideal antenna placements

- Antennas must be high above ground and receive from all azimuth directions
- Antennas must be unobstructed, $>3 \times$ size
- Minimum coupling with other metallic structures or antennas
- Distance to receiver (cable-length) short
- Distance to spurious emissions as large as possible
- Some antenna types require large ground plane, either galvanic connected or coupled
- Polarization of the transmitted service and antenna shall be considered

3. Overview on vehicular antenna placements

Watching different cars on the road in terms on antenna placements, it seems that there are a number of placements to be found.

Figure 1 displays the best practices to place antennas to vehicles.

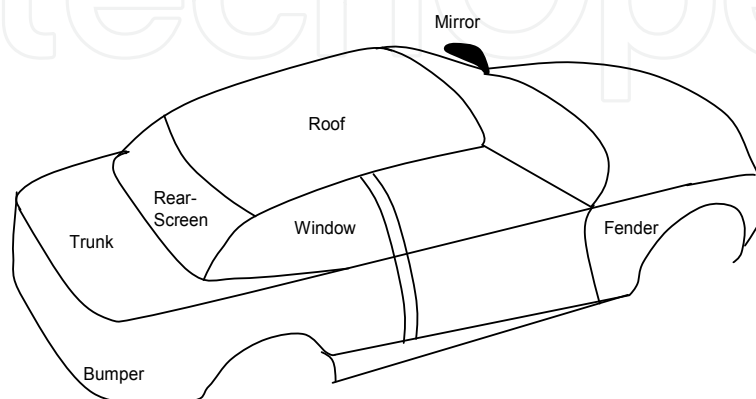


Figure 1. Suitable antenna placement on a regular passenger car

3.1. Roof

Most car manufacturers use the roof to place an antenna. This has an obvious reason, because the roof of a car is the high above ground and unobstructed. This provides a good reception into every direction. Mostly, omni directional reception is required anyway, so placing the antenna on the roof is one of the best options for most of the vehicles, except convertibles.

3.2. Spoiler

Some sportive cars exhibit a spoiler for better down force on higher speeds. When the spoiler is made of plastic, it can be used to place antennas inside. Racing cars use this technique for telemetry communication.

Regular hatchback cars can have a little spoiler, in which a number of antennas can be implemented. This method works exceptionally well and is the second preferred place, whenever a spoiler is present.

3.3. Screens and windows

Placing antenna structures into windscreens, side windows or rear-windows has become very popular for premium car manufacturers since 1980. As most cars have glass windows, to which an antenna structure can be applied, it is a cheap but effective method. Here the antenna structure can be either on the glass or along the frame. The glass itself is usually big enough to inherit large antenna structures or many different antennas. On-glass antennas require a larger engineering effort but can be manufactured with low costs once the structure is developed. Especially when the design of a car is of importance and roof antennas would not suite aesthetic aspects, then on-glass antennas is the way forward.

3.4. Fender and bumper

Some of the fenders or bumpers are made of plastic, which suite for placing the antennas behind as they can offer enough free room. However, special care must be taken for easy repair, as bumper and fenders can crash. Also take into consideration that engine noise and low height above ground might degrade antenna performance.

3.5. Trunk cover

Alternatively to the roof, the trunk cover is a suitable position to contain a number of antennas. Especially for convertible vehicles, where the roof and screens can be hidden, the trunk cover is advised to place antennas into. However, the trunk cover must be made of plastic or a double-layer structure with metal frame and plastic cover on top.

3.6. Mirrors

Light trucks and sport utility vehicles (SUV) offer huge side mirrors in comparison to normal cars. The shell of the mirror is mostly plastic. Inside these mirrors a number of

higher frequency antennas can be placed. Some truck side mirrors are large enough to inherit a combination of FM-receiving antenna at VHF-band, Telephoning antenna from GSM and CDMA systems, a GPS navigation antenna and on top a SDARS satellite broadcasting antenna. Regular vehicle side mirrors can offer some space for higher frequency services above 1 GHz, e.g. Car-2-Car communication at 5,9 GHz.

3.7. Summary of ideal antenna placements

There are many positions possible to place antennas on a vehicle, but not all are good for each type of car. For good reception of wireless systems, there are a number of factors to be considered.

As stated in the chapter 2 on general requirements, the antenna must be as high as possible above ground for long path transmission. The antenna must be unobstructed to communicate into all directions well.

Combining both prerequisites translates into the rule of thumb, that antennas shall be operate as freely as possible, which means, the more an antenna packed into a structure, the less efficient it is.

Some antenna structures are easier to handle even in tight environment and some antenna technologies are very fragile in terms of antenna characteristics in tight metallic surroundings. Selecting the appropriate antenna structures helps finding a compromise between antenna position and performance.

4. Overview on possible antenna technologies

Antennas can be placed on the vehicle on many places, but only a few positions are ideal. To define which position is ideal, this must be considered for the service and frequency band as well as in conjunction with selected antenna technology. Here we give a short overview about the most popular antenna technologies

4.1. Monopoles

Monopole antennas are the most popular antenna type, as they are very easy to handle, easy to manufacture, easy to implement to the vehicle and very cheap.

A monopole antenna consists of an antenna foot and the rod of some length. Placing the antenna on the roof of a car requires just a hole in the metallic structure for the antenna foot and the cable to be attached.

The rod can be a stiff metallic stick of a quarter wavelength ($0,25 \cdot \lambda$) or longer. There are rods which are telescopic or even flexible. Monopoles provide a broad range of applications in every frequency band, from VHF sound broadcasting up to car-2-car communication at 5.9 GHz. The monopole can be placed in the roof center, on an edge of the roof or on the frame, or even on a bumper or fender. This antenna technology is quickly implemented to

nearly anywhere on the vehicle. In conjunction with a very competitive pricing due to quick development and easy manufacturing, monopoles are the first choice in the automotive industry.

The monopole antenna requires a direct connection to ground, meaning the metallic structure of the vehicle. The monopole will not work efficiently when the metallic ground is small in comparison to the wavelength λ . Minimum $0,25*\lambda$ is required for ground plane to neglect effects.

However, aesthetically speaking, the rod antenna on a roof or fender does not satisfy modern design emotions, so car designers try to avoid simple rod antennas on their cars. Especially for premium car manufacturers, rod antennas are meant to be avoided in modern car antenna system concepts.

4.2. Patch antenna

In principal, a patch antenna is a flatted monopole. Figure 2 shows the principal structure of a patch antenna. A metallic plate of about half wavelength ($0,5*\lambda$) is placed over a metallic ground plane, which are separated either by air or a low loss dielectric material. The RF is ideally fed directly to the radiating patch.

This antenna type is becoming more and more popular in the automotive industry. At first just for high frequency applications beyond 1 GHz, such as for GPS reception at 1,5 GHz or SDARS satellite broadcasting radio reception at 2,3 GHz, WLAN and Car2Car Communication at 5-6 GHz, but nowadays increasingly seen for telephoning antennas for GSM and CDMA at 800/900 MHz.

As this antenna type is unobtrusively flat and can be implemented into the vehicles structure, e.g. behind a fender or bumper or in a plastic trunk cover. Patch Antennas require a large metallic ground structure, preferably flat of minimum $1*\lambda$ around the antenna. If the vehicle cannot fulfil this requirement at the position with its surrounding metallic structure, then the patch antenna shall provide its own ground plane in the antenna structure.

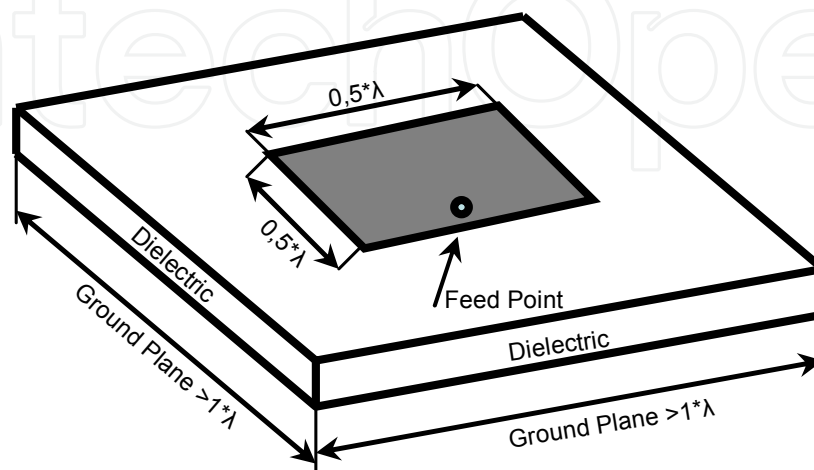


Figure 2. Principal structure of a squared patch antenna

4.3. On-glass antenna

This antenna type became popular in the premium car industry in the 1980, when design topics became increasingly important. With on-glass antennas it becomes possible to hide a number of antennas for the regular user's eye. As most vehicles have glass windows, an antenna structure can be implemented there.

The most straight forward antenna technique for on-glass follows a slot antenna principle. Here the metallic car structure becomes part of the antenna and the glass (windscreen, side window or rear window for example) is used as the slot in the metallic structure. Coupling this slot with a thin conductor, the slot resonates and can be used as antenna. The feeding position is of some importance. With a clever selection of the feeding position, different modes can be activated, which can help to excite certain polarities or radiation behaviour.

Figure 3 shows the slot antenna principle which explains on-glass antenna function.

As defrosting conductor elements are already placed to the rear window, these conductors can be applied for such on-glass antenna structures. Here, a simple filter is used to separate the DC-current for defrosting from the radio frequency (RF).

The development of such on-glass antennas can take some time, as car structure and glass window holes in the metallic structure are both parts of the antenna jointly, which influence each other. So changing the shape of the car will change the on-glass antenna characteristics. But once a suitable structure is found, the manufacturing process is very cheap.

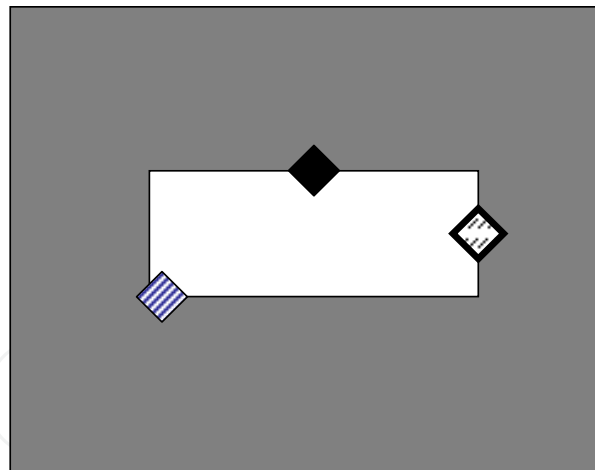


Figure 3. Slot antenna principle for on-glass antennas. Different feed point options are indicated which excite different modes for special radiation characteristics

4.4. Glued foil antenna

Similar to slot antennas and patch antennas, these structures can be placed on metallic foil, which is glued to a plastic element.

So very flat antenna structures can be produced, which can be placed into rear-view-mirrors, side-mirrors, spoilers, bumper and fenders or any non-metallic parts of the vehicle.

However there are some disadvantages to be mentioned, which are the very narrow usable bandwidth and the problem to connect coaxial cables to the flat foil antenna. In addition, moisture and spray water shall be avoided.

The connection problem is often solved by coupling the signal to the structure, but losses must be taken into account. The structure shape is virtually unlimited so that a huge variety can be found in books and journals.

Figure 4 shows one example of foil antenna structure.

4.5. Fractal antenna

A very modern field of antenna technology is summarized as fractal antennas. It has been found that not only some structures repeat their resonance with $n \cdot \lambda$, but also when repeating the structure in itself. This fractal breakdown of a wire structure or a patch antenna structure leads to multiple resonances of the antenna. When tuning the structure that many frequency ranges can be used, only one antenna could be used to serve most of the required services.

As the benefit is that only a few antennas need to be placed, which is good for small cars, the disadvantage is the very limited usable bandwidth where the structure resonates.

Figure 5 shows an example of a fractal antenna principle.

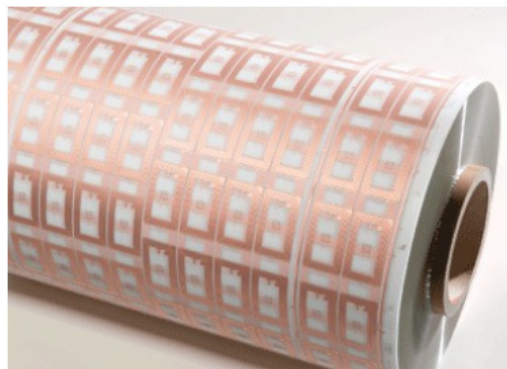


Figure 4. Thin foil antenna structures on a roll

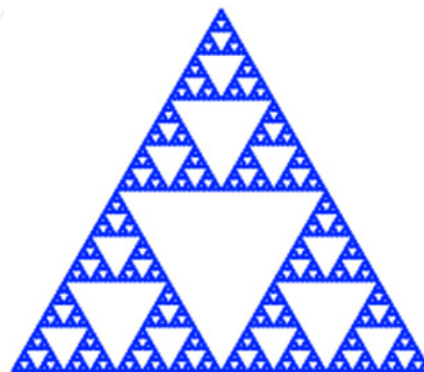


Figure 5. Sierpinski fractal antenna structure

5. Selecting antennas according to services

Broadcasting systems reign a long history so backward compability is a major requirement also for modern cars. Although the number of mobile shortwave listeners is very limited, each car entertainment system offers shortwave-reception.

Table 1 summarizes the existing broadcasting systems.

5.1. Short- and medium wave bands

Short wave (SW) and medium wave (MW) band provide a worldwide coverage due to ground wave propagation and wave reflection at ionosphere layers in the atmosphere. As these layers are approximately 80 km to 300 km high, a large distance can be bridged. For large-area countries such as Australia, Brazil or Canada just to name a few, a nation-wide broadcasting coverage can easily be done on MW-bands. From history we adopted AM-modulated signals with relatively poor sound quality, compared to today's quality expectations. Vehicular SW-antennas are difficult to implement, as the car is always too small even for quarter wavelength antennas. So an electrically shorted monopole must be used then, which is applied as rod antenna. In some occasions the rear window or a plastic spoiler can be used.

5.2. Digital Radio Mondiale (DRM)

In order to overcome poor sound problems in SW/MW-bands, transmission became digital. Digital Radio Mondiale (DRM) decodes sound information to a digital data stream which is modulated with OFDM and broadcasted on SW/MW-bands. The receiver can decode this data stream and correct transmission errors. The sound quality is intuitively better than analog broadcasting but coverage is found to be reduced. That is mainly due to the fact that digital wireless systems have an abrupt go-nogo border, while analog systems degrade gradually until signals disappear in noise [1].

5.3. VHF-band and UHF-band

Around 1950, VHF-frequency spectrum was utilized in Europe. Radio propagation in 100-MHz-band can reach approximately 30% beyond the optical horizon, so called radio horizon. This leads to a limited coverage of sound or TV broadcasting stations. Depending on transmitter location and radiated transmit power the typical coverage area is about 100 km². For a nation wide broadcasting network, a high number of transmitters must be installed. Especially in hilly terrain uncovered areas occur due to radio shadows. When reception is needed there, filling transmitters are needed. On VHF-band (76-109 MHz) sound broadcasting is transmitted while on UHF-band (400-800 MHz) TV-broadcasting is located. Typically, a dual layer broadcasting network is rolled out in VHF- and UHF-bands. The first layer consists of transmitters with high power on prominent locations, covering a large area. The second layer fills coverage gaps with low-power transmitters.

As each transmitter requires a separate frequency in order not to interfere with each other, the dedicated frequency spectrum is quickly used up. Clever frequency allocation and frequency reuse is needed.

For VHF and UHF a number of antenna techniques can be used. The cheapest version is using a monopole, but on-glass slot antenna structures offer a very efficient way as well. If the vehicle has a plastic spoiler or a plastic fender/bumper, it can inherit VHF/UHF antennas.

5.4. Digital broadcasting systems

In 1987 development of digital broadcasting systems began and a number of digital transmission standards derived since then. Digital Audio Broadcasting (DAB), former Eureka-147 Project, was the start into digital data processing and digital broadcasting transmission. DAB decodes sound information to a digital data stream which is modulated with 4-PSK-OFDM and broadcasted on VHF-band. The receiver can decode this data stream and correct transmission errors. The sound quality is intuitively better than analog broadcasting. Similar to all other digital wireless systems, DAB reception is experienced having an abrupt go-nogo border, which is often misunderstood that coverage is smaller than analog systems [1].

One of the benefits of digital broadcasting system is that more programs can be transmitted with one frequency allocation. While in analog broadcasting one radio station used one frequency, now up to 64 radio stations can be received on one single frequency. This offered new broadcasting capacity for more divert channels covering more genres and clientele. Another benefit of digital transmission is the higher sound quality.

With better coding capabilities using MP3 and MP4 codecs a more efficient transmission could be implemented. Digital Multimedia Broadcasting (DMB) is using MP4 AAC+ codec in contrast to DAB, where MUSICAM codec is implemented. For video transmission, Digital Video Broadcasting (DVB) is used. DVB is similar to DAB and DMB, except that video signal compression H.264 is added to sound compression algorithms and higher intrinsic modulation schemes are used, often 16QAM-OFDM. DVB is successively replacing analog TV-transmitters in Europe.

The placement for DAB antennas shall be properly selected, keeping the spurious emission noise in mind.

5.5. IBOC system

In USA, another method of digitalization is used. Beside the analog modulated signal, an additional digital modulated signal with same content is transmitted, so called in-band on channel (IBOC) signal. Figure 6 displays the spectrum of such an IBOC signal.

Having good reception, the tuner decodes the digital information and provides high-quality sound. Reaching the go-nogo-border of digital transmission, the tuner switches to

traditional analog broadcast. The listener may observe a small degradation in sound quality but is still able to follow the program.

In Europe, IBOC was tested in Switzerland in a range limited test environment [2]. It is unlikely that IBOC will be introduced in Europe, as VHF-band channel raster of 200 kHz interferes with US-IBOC channel bandwidth requirements of 400 kHz. To fit into the existing channel raster, one of the redundant digital sidebands can be removed. This method is known as FMeXtra and is currently under test in a testbed [3].

For IBOC receiving systems, the selection of suitable antenna structures are identical as VHF/UHF systems, but due to accompanied digital sidebands, the spurious emission noise must be considered when placing the antenna, similar to DAB systems.

5.6. Satellite Digital Audio Radio System (SDARS)

For large area countries such as Australia, Brazil, Canada, Russia or USA, just to name a few, traditional nationwide terrestrial broadcasting systems are very expensive to install. Using low orbit satellites offers an efficient nationwide coverage. In USA, Satellite Digital Audio Radio Systems (SDARS) in 2.3-GHz-band was implemented and succeeded with a sheer overwhelming number of different programs for all sorts of listeners. Even a monthly fee could not stop listeners to attend SDARS in USA.

Above 1 GHz there are patch antennas first choice. As GPS and SDARS is transmitted from satellites high above ground, the antenna shall receive from sky best, which limits the placements to be 360° unobstructed to sky. Hence the roof and exposed spoilers are suitable positions, in some occasions mirror housings as well. Convertible cars can utilize the trunk cover or the upper edges of the fender.

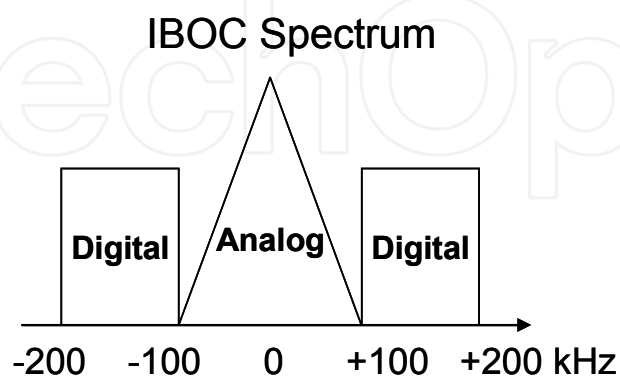


Figure 6. Spectrum of IBOC system with analog and digital modulation containing identical information

System Name	Abbreviation	Frequency Band	Modulation
Long-Short-Medium Wave	LW/MW/SW	172 kHz - 30 MHz	Amplitude Modulation AM
Ultra short Wave	VHF	76 MHz - 109 MHz	Frequency Modulation FM
In-Band On-Channel	IBOC	76 MHz - 109 MHz	Quadratur Phase Shift Keying, QPSK
Digital Broadcasting System	DAB	174 MHz - 210 MHz	Orthogonal Frequency Division Multiplex, OFDM
Digital Broadcasting System with enhanced codec	DAB+	174 MHz - 210 MHz	Orthogonal Frequency Division Multiplex, OFDM
Digital Multimedia Broadcasting	DMB	174 MHz - 210 MHz	Orthogonal Frequency Division Multiplex, OFDM
terrestrial Digital Video Broadcasting	DVB-T	480 MHz - 860 MHz	Orthogonal Frequency Division Multiplex, OFDM
terrestrial Digital Video Broadcasting with enhanced codec	DVB-T2	480 MHz - 860 MHz	Orthogonal Frequency Division Multiplex, OFDM
Satellite Digital Audio Radio System	SDARS	2,30 GHz - 2,33 GHz	Orthogonal Frequency Division Multiplex, OFDM

Table 1. Overview of broadcasting systems

5.7. Best practices - Where to place antennas for services

When looking at various vehicles on the market, there will be seen a number of antenna solutions on the vehicle structure. The most popular antenna placement is a monopole rod antenna on the roof of the car, as this method fulfils the most important basic requirements, high above ground and unobstructed.

The radiation characteristic is quasi omni directional, when the metallic roof is large enough. For frequencies >100 MHz, which refers to FM-broadcasting reception, TV-reception and mobile telephoning systems, monopole antennas on vehicle roof are perfectly suited.

In addition, they are very easy to implement and with about 5 EUR or less per piece very cheap. These are the reason why the majority of the vehicle manufacturers apply monopole rod antennas.

Sometimes the car designer does not like antennas on the structure. Then hidden antenna concepts must be used. A very common way is to place the antennas into a plastic spoiler. As the spoiler is usually high above ground and unobstructed for good airflow, it fulfils basic requirements for good reception. Racing cars use the spoiler structure for telemetry communications. Sometimes regular hatchback cars contain a spoiler, into which VHF-antennas for sound and TV broadcasting, GPS-antennas and nowadays Car-2-Car Communication antennas can be easily integrated. Of course it is also possible to apply telephoning and satellite broadcasting SDARS antennas into spoiler structures.

When there is no sportive spoiler but the design aspects require invisible antennas, the antennas can be placed into the screens. Here the slot antenna concept is used, which requires some development but once the structure is found, it is easy and cheap to manufacture. Usually the rearwindow is used when the engine is in front, offering the

maximum distance from spurious emission noise. In rare occasions where the engine is in the backside of the car, e.g. Porsche 911 model, then the windscreen is used. However, the antenna structure shall not effect visibility then.

Alternatively sidewindows can be used for antenna structures but often they are too small for multiple antennas and VHF-antennas.

As foil- and fractal antennas became popular for mobile phone antennas, this concept has also been applied to the car industry. Today we find fractal foil glued antenna structures in rearview mirrors, e.g. garage door opener, car entry systems and Bluetooth- / WLAN antennas, just to name a few.

Light trucks and SUVs comprise some large side mirrors, in which even low frequency antennas can be placed, such as for FM-reception on VHF bands and mobile telephoning systems.

The only disadvantage is that in a case of an accident with damaging the side mirror, the wireless service can be damaged as well or reception becomes poor.

In order to avoid a complete loss of service, either both side mirrors can be equipped or a combination with other antenna locations can be used.

The side effect of this method is that multiple antennas can provide better reception. This method is known as diversity reception.

6. Diversity - Combating fading

In vehicular receiving environments fading of signals occur due to multipath reception. When a radio signal is transmitted, it reaches the receiver on a direct path as well as on reflected paths from buildings, landscape and obstructions, see Figure 7. The reflected paths reach the receiver at different times than the direct path. This leads to superposition of multiple signals of the same content. Signals can add or subtract each other at the receiving zone, leading to a varying loudness impression in amplitude modulated signals and signal dropouts in frequency modulated signal. In digital systems, bit errors can occur.

A number of methods were invented to reduce the audible effect of multipath fading.

One method is to apply a number of receiving antennas on different positions of the car. Different antennas at different locations are assumed to receive different signal components. This effect is known as spatial diversity. A switch selects the best receiving antenna according to the signal strength and noise level. Figure 8 shows the principle of switching spatial diversity for VHF-FM reception. Another method is to use both tuners in a dual-tuner concept which are connected to individual antennas. Due to the different location of the antennas phase differences occur which are corrected by phase shifters. Then, both phase corrected receiving signals can be added in-phase and can prevent fading dropouts. This method is known as phase diversity.

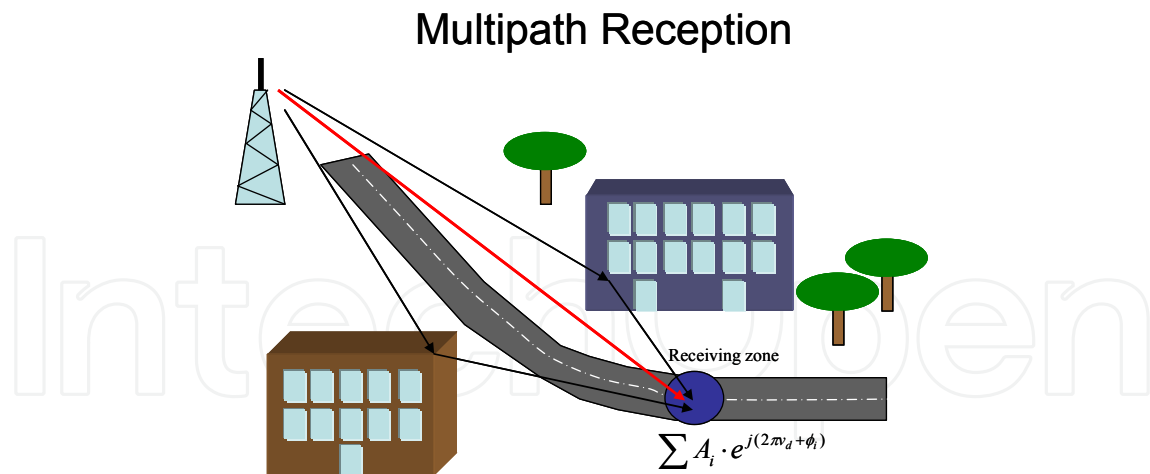


Figure 7. Principle of multipath environment where transmitter signal is reflected, diffracted and attenuated by environment. At the receiving zone signal paths are summed.

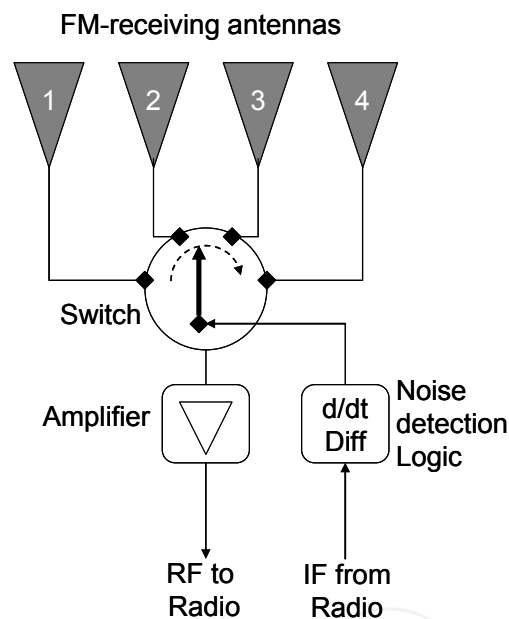


Figure 8. Principle of switched diversity in modern tuners [1]

In digital broadcasting systems, bit streams can be combined to correct transmission errors. Here, two receivers operate individually but synchronized by internal clocks. The digital data streams are compared with each other and bit errors corrected when necessary. The combined data stream provides a more consistent data rate which results in a better quality of service for the listener. Figure 9 shows principle bit stream diversity for DAB.

6.1. Best practices - Where to place diversity antennas

When placing diversity antennas, there must be some requirements to be fulfilled.

The main requirement is that antennas used for diversity reception must be mutually decoupled, meaning that one antenna shall not receive the identical signal than the other,

better to receive a different phase or a different component of the signal. Only then the fragments can be assembled to a better signal. To achieve this, different antennas shall be placed at least 3 wavelength apart, so that signal can be received at the different time and different phase. This method is known as “spatial diversity”. If there is not enough space for a large gap between antennas, an alternative is to receive different phase components, which is known as “phase diversity”. In a premium vehicle, diversity reception for FM or TV is achieved with a combination of phase and spatial diversity. For instance, placing 2 antennas in the rear-window, one is vertically dominated polarized, the other horizontally dominated polarized. Both rear-window antennas provide good reception, as nearly all phase components of the multipath signal can be received.

However, having both antennas in the rear of the vehicle, the reception to the front side can be shadowed. This can be overcome with a third antenna, either a monopole on rooftop or a structure in the spoiler (if the vehicle has one) or using a structure in the front fender. For higher frequency ranges, the mirrors can be used, e.g. fractal foil structure glued to the plastic housing.

Combining rear-window and side-mirror antennas, a fully decoupled but omni directional reception is achieved where most of the multipath signal components can be processed.

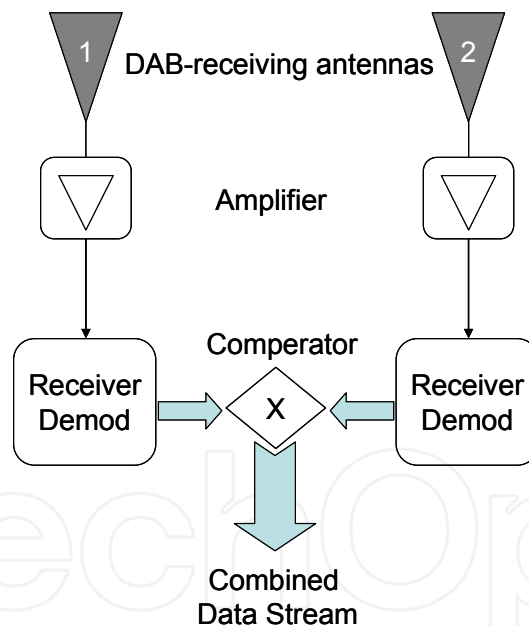


Figure 9. Principle of bit stream combining method for digital broadcasting systems [1]

7. Outlook and future trends

From the performance point of view, a lot can be optimized in the entertainment system in the future. Especially broadcasting reception is deemed to be improved. Historically, the tuner was installed in the center console, while the receiving antenna was on the fender. The cable length was comparably short. A disadvantage of this solution is that engine spurious emission noise is easily picked up by the antenna and disturbs reception.

Modern cars however offer a number of receiving antennas for diversity reception in the rear-window, side-window, bumper and fender for instance, but long cabling ways attenuate RF signals.

The wide range of broadcasting standards requires multiple tuners buried in the car. Integration and size reduction is a major playground in R&D departments. Transceivers of modern mobile phones are approximately 30x30 mm² or less and 3 mm thick, offering multi-frequency and multi-standard operation already. With SDR-tuners it will become possible in near future to provide compact multi-standard broadcasting receivers exploiting diversity gain by MIMO concepts. This allows integrating such receivers into - or at least close to - the antennas. Reception performance will improve drastically unless EMC problems occur.

Another mega trend of this decade is a permanent internet connection. With UMTS and WLAN it is already possible to connect laptops and mobile phones to the internet while riding in car. In near future, the vehicle itself gets connected to the internet. The mobile phone standard Long-Term-Evolution (LTE) will support this trend. The merge of internet services and vehicular entertainment functionality will provide efficiency and convenience to the passengers. The sheer endless list of new service ideas for the drivers and passengers is overwhelming and becoming unique selling points for car manufactures. They will offer new services to drivers, from intelligent traffic routing, parking aid to firmware updates inside the car. Passengers will be able to stream music and videos as well as communicate while surfing the internet.

In conjunction with passenger entertainment, Car-2-Car Communication systems offer new information sources for the driver to plan a trip and offers new safety features during the ride.

One of many applications is that traffic flow is constantly monitored by ego-speed history and current data recognition, which will be broadcasted to other vehicles on the road nearby. Comparing own speed information and vehicles in front of own position allows a rolling "look-ahead" traffic situation estimation of the upcoming path. This will help to adjust driving speed to enable a better traffic flow as well as avoid traffic jams.

Another safety aspect of C2C information exchange is on crossroads. Here a central station receives signals from vehicles approaching and can guide them through the cross-traffic. With this, right-of-way accidents can be reduced as well as traffic flow improved.

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