Automotive Hexband Antenna for AM/FM/GPS/SDARS and AMPS/PCS1900 Cell Phone in an only 65 mm high Housing

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Abstract. Nowadays cars are equipped frequently with typical 400 mm long active AM/FM antennas mounted on top close to the rear windshield. In [1], we presented a novel capacitive coupled helical antenna with a height of only 140 mm which performs equivalent to such an 400 mm long antenna. In the next step the antenna height has been reduced to only 56 mm in order to be placed in a low 65 mm housing in combination with other decoupled antennas. The measured results for AM/FM are close to the performance of a whip antenna of 900 mm length. The GPS and SDARS antennas are realized in a combination of two table-formed ring structures with a maximum gain for LHCP at 2339 MHz with 2.9 dBi in zenith and with 5.2 dBi in zenith for RHCP at 1575 MHz with GPS. The VSWR of the cell phone antenna is below 3 for AMPS and PCS1900.

1. Introduction
For 60 years cars have been equipped with rod antennas with a typical length of 800 to 1000 mm usually mounted on a fender of a car for AM/FM reception. At the beginning of the 1970s they were replaced more and more by transistorized active 400 mm long rod antennas mounted on top of a car near the rear windshield. Since 1984 active AM/FM antennas have been integrated inconspicuously in the windshield using extremely thin wires in the laminated safety glass or in the backlite using the heating structure as antenna element. With increasing demand for cell phone antennas at the beginning of the 1990s, compact antennas were installed in small housings on top of the car near the rear window. Antennas for satellite radio reception in the S-band as well as antennas for GPS navigation were implemented frequently in such housings with a height below 65 mm. For some years active helical antennas have been on the market with a height of 200 to 300 mm. In [1], we presented a novel capacitive coupled helical AM/FM antenna with a height of only 140 mm. But it is very tremendously challenging to implement an AM/FM antenna in a housing of only 65mm.

2. Automotive Hexband antenna design principle
In figure 1 the new hexband antenna design principle is displayed. As AM/FM antenna element a capacitive coupled helix antenna is applied.

Figure 1. Automotive Hexband Antenna in an only 65mm high housing.
which has been extended in the form of a horizontally arranged meander to form a top-loaded antenna. This AM/FM antenna element is connected to separated amplifiers with capacitive high input impedance for AM and FM and is placed in the center of the SDARS/GPS antenna. As a result the performance of the SDARS/GPS antenna is not affected by the AM/FM antenna element at all. The SDARS and GPS antenna are realized in a combination of two table-formed ring structures with outer dimensions of only 39 mm x 39 mm x 10 mm [2] and are connected to separated low-noise amplifiers. The inner antenna for SDARS application has vertical elements for reducing the physical dimensions. A short cell phone antenna for AMPS and PCS1900 is integrated in the small housing, too.

3. AM/FM reception

The novel capacitive coupled helical antenna (CCHA) is only 56 mm high in total and consists of a copper helix with constant pitch, wound on a dielectric tube with a diameter of 6mm (Figure 1). The lower end of the helix, isolated by a thin dielectric layer, is inserted in a cylindrical socket without having any galvanic contact with it. This socket is extended by a thin pin in order to be connected to the AM/FM amplifiers. The top end of the helix is continued to the right and left side with a bare wired meander structure, which is transparent for GPS and SDARS frequencies.

3.1. FM reception

The antenna impedance has resonant character in the FM range (87-108 MHz) and is displayed in figure 2. Therefore a specialized FM amplifier is necessary. The design principle of such a high input impedance amplifier is shown in figure 3. For FM, a two-stage amplifier is used, consisting of a GaAs HEMT transistor as source follower and a bipolar transistor employed in common base. In between both transistors a passive frequency flattening network is implemented in order to attenuate the resonances caused by the antenna in combination with the amplifier’s capacitive high input impedance. An additional AGC network can be implemented here, too. The amplifier’s gain is about 13dB, the noise figure less than 3dB. The output noise floor is below -5 dBµV at a bandwidth of 120 kHz. In order to keep off the flicker noise of the HEMT from the AM stage, a series resonant circuit with a low capacitive value \( C_s \) is applied in combination with a FM choke \( L \). The dynamic range of the AGC comprises 27 dB and starts at 95dBµV input level. The \( k_3 \) intermodulation product is 60dB below at each tone input level of 95 dBµV. The output VSWR is less than 2.

In order to evaluate the signal performance, field measurements are done with the active antenna mounted on top of a car above the rear windshield. The car is placed on a turntable and the values are averaged for a complete rotation of the car. In order to account for the particularities of the measurement setup, the results are compared to the ones obtained with a 900 mm passive monopole reference antenna mounted on a front fender of the car. The results plotted in figure 4 show the ratio of the signal delivered by the new antenna design to the signal delivered by the reference antenna for both polarizations. For horizontal polarization the mean value lies only -2.5 dB below the rod antenna and at -1.5 dB with vertical polarization from 87 to 108 MHz.
3.2. **AM reception**

For a good AM performance it is obligatory to reduce capacitive loading by the amplifiers to an absolute minimum due to the low antenna capacitance. Therefore the AM amplifier is designed as a FET cascode followed by a buffer stage in order not to deteriorate the output signal level by using a long 50 Ohm coaxial cable to the receiver. At the input of the AM amplifier the FM choke $L$ forms a low pass filter together with the input capacitance $C_{\text{FET}}$ of the FET (figure 3). The filter prevents the full FM signal from reaching the AM stage. The designed AM amplifier fulfils the requirements [4] with respect to gain ($R_D/R$), noise floor, intermodulation behaviour and output compression point. Field measurements show that the signal levels achieved with the new antenna design is 2 to 3 dB in the LW and MW frequency range better than with a 900 mm long rod antenna.

4. **SDARS and GPS reception**

4.1. **Antenna Principle**

For the reception of Satellite Digital Audio Radio Services (SDARS) and Global Positioning Systems (GPS) a combination of two metal sheet antennas is used [3]. Both antennas have a ring structure at the top and vertical elements for reducing the physical dimensions [2]. This ring structures have an electro-magnetic length of exactly lambda at their main frequency. Therefore, the positive potential and the negative potential are always on opposite sides of the ring structures while the wave is circulating. In the geometric center of the ring antenna combination of this SDARS antenna and GPS antenna, the potential is always zero. This is the reason why it is possible, to integrate the AM/FM antenna structure in the geometric center of the SDARS-GPS antenna combination.

4.2. **Design Principle**

The SDARS- GPS antenna combination is realized in a combination of two table formed metal sheets with a ring at the top, vertical elements and capacitors to ground for reducing the physical dimensions. Therefore the volume with plastic socket is only 39 mm x 39 mm x 10 mm. The feed point for the SDARS antenna and the GPS antenna coupled with small matching networks and Low Noise Amplifiers (LNA) are positioned at the rear side of the circuit board. With perfect matching at 2339 MHz the inner SDARS antenna reaches a bandwidth of more than 50 MHz. The outer GPS antenna has also a bandwidth which exceeds the necessary bandwidth significantly. Cause of this metal sheet design of the SDARS-GPS combination in a plastic socket, the antenna combination is easy to fabricate, has a high reproducibility and low losses.

4.3. **Antenna Measurement**

The measurement results for the SDARS and GPS antenna were performed in an anechoic chamber with a distance of 5.45 m between the transmitting standard horn antenna and the Antenna Under Test (AUT). The AUT is mounted on a circular metallic plate with bent edges and a diameter of 1.2 m. In figure 5 the measurement results for the SDARS antenna are shown. The graph shows the gain for LHC polarization and RHC polarization in 36 azimuth cuts. The maximum gain for LHC polarization reaches 2.9 dBiC in zenith. The SDARS antenna offers also a very high vertical gain. The linear average gain over phi, of the vertical polarization between theta = 75° and theta = 90° is – 0.51 dBiL. The LNA offers a gain of 31 dB with a noise figure of 0.65 dB.
Figure 6 shows the measurement results for the GPS antenna. The graph shows the gain for RHC polarization and LHC polarization in 36 azimuth cuts. The maximum gain for RHC polarization reaches 5.2 dBic in zenith. The LNA offers a gain of 30 dB with a noise figure of 1.5 dB. The efficiency of both antennas is about -1.5 dB.

5. Cell Phone Antenna
A short monopole antenna serves as cell phone antenna for AMPS and PCS1900 e.g. in the US. The lower part of this 2 band antenna is used for the higher PCS1900 frequency band, the upper part is connected via a printed series resonant circuit for the lower AMPS frequency band. In both frequency bands the VSWR is below 3 without applying a matching network.

6. Mutual Coupling
The mutual coupling between the antennas is for every used frequency range less than \(-20\) dB except the coupling between the AM/FM antenna and the cell phone antenna. A filter with very low capacitive values in front of the AM/FM amplifier suppresses the cell phone signals with 30 dB.

7. Summary
An automotive hexband antenna for AM/FM/GPS/SDARS and AMPS/PCS1900 cell phone in an only 65 mm high housing is investigated. Compared to a 900 mm long rod antenna the AM/FM antenna shows in field measurements for FM nearby the same performance and for AM even better signal levels. The SDARS-GPS antenna combination has been realized with the AM/FM structure in their center without influencing each other. The SDARS and GPS antennas achieve a high gain for satellite reception for both services. For cell phone, the VSWR reaches less than 3 in both frequency bands.

References
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