# Printed Antennas for Automotive Applications

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**To integrate printed antennas in plastic body parts of automotives for the reception of electromagnetic waves such as AM/FM, GSM and many more is a very promising alternative to the standard rod antenna or to experiments with cut out copper foils. This is true not only to performance reasons - what is shown in this paper - but also for cost reasons. The antennas are printed on plastic films (carrier) which can be transferred to the plastic body parts. By over-moulding slight 3-D designs can be accomplished and the antenna as well as the carrier are completely integrated in the plastic part. The compatibility of the materials and performance (printing, processing and electrical) is tested thoroughly as described in this paper. Further, some examples for applications in cars and agricultural vehicles are shown.**

## Integrated Antennas: Idea

In order to receive broadcast signals appropriate antennas are needed. For radio reception in vehicles conventional antennas need to be placed at the exterior of the car because the cars sheet metal shields the electromagnetic signal. Thus, there is a requirement of drilling holes into the sheet metal, place parts outside the cars body and connect them by wiring.

Nowadays in car design more and more plastic parts are used. Plastic does not shield the signals. Thus, the idea is to integrate antennas in those plastic parts (hidden at inner side) without damaging or influencing the "class-A" surface of the car. Further, modern communication by radiation broadens the range of frequencies that must be received or in some cases, also sent out.

The classic rod antenna is simple but not sufficient for such an extreme wide range of frequencies. Therefore new antenna designs are desirable. Fig. 1 shows the transition to the integrated antenna concept.

A lot of possible placements in the plastic parts can be considered as shown in fig.2 (station wagon). Especially interesting with usually more plastic parts are convertibles as depicted in fig 3.

The realization of this fascinating idea of integrated antennas, however, is the challenge. First tests with cut out self-adhesive copper strips (fig. 4) showed that there were

- high amounts of waste
- marks on the outside that could be seen through after over-mould

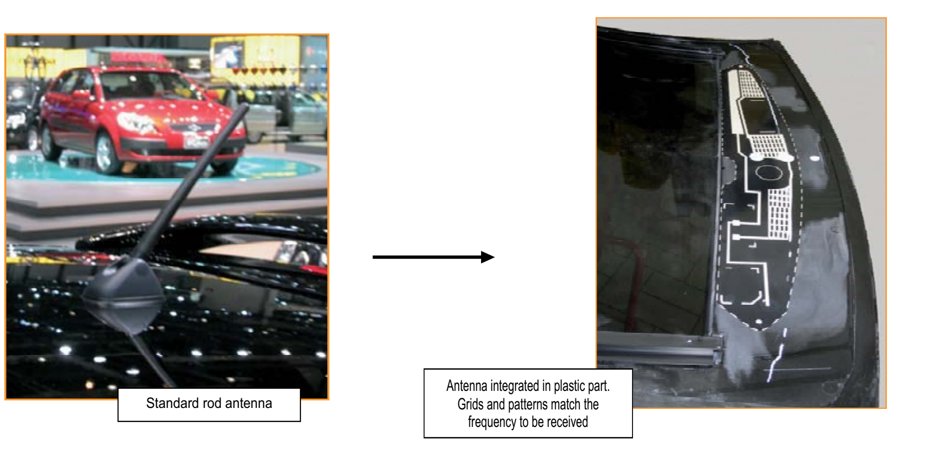


Fig. 1: Transition from rod to integrated antenna

- adhesion problems caused by different plastic body part surfaces and materials
- oxidation of copper which endangers conductivity
- rather high costs

Overall, this solution is not quite suitable for a serial process.

The solution that worked and what was proven during a diploma thesis at the HdM was: printing! However, there are ambitious requirements that must be met:

First of all antennas must be (highly) conductive. The ohmic resistance should be in the range of a few hundred milliohms. Depending on the specific conductivity of the available conductive inks a layer thickness of about 10 to 20µm at a line width of about 3mm are sufficient. Thus, the printing technique that fits best to meet this requirement is screen printing.

Further, the printing technology offers very flexible and variable layout which leads to a perfect adaptation of the amplifier to the antenna. The project from which is reported here therefore has an almost perfect symbiosis combining the expertise in electrical and outline design of an antenna with the screen printing know how of the Stuttgart Media University (HdM). All prototyping is done at the HdM whereas the antenna layout as well as the matching amplifier is computed and designed by Hirschmann Car Communication (HCC). Once a product and manufacturing recommendation have been worked out the final production run printing is done in print shops with high excellence.

The complete screen printing form preparation is done at the HdM. For imaging CAD-data are used and plotted on an Epson inkjet printer onto a special transparent film (fig. 5). The optical density is sufficient for a contact copy onto the light sensitive emulsion coated on the screen and the plotter's resolution is absolutely sufficient for the comparatively course antenna layouts.

## Research Work

In the beginning of the project several possible alternatives of applying the printed conductive structure to the plastic part have been considered. It could be either direct print (as in the example in fig. 1) or print on a film (carrier) and attach it later on to the body part. The sub carrier offers four

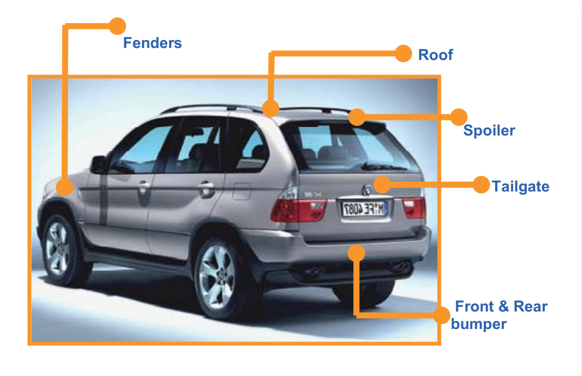


Fig. 2: possible antenna placements in a station wagon

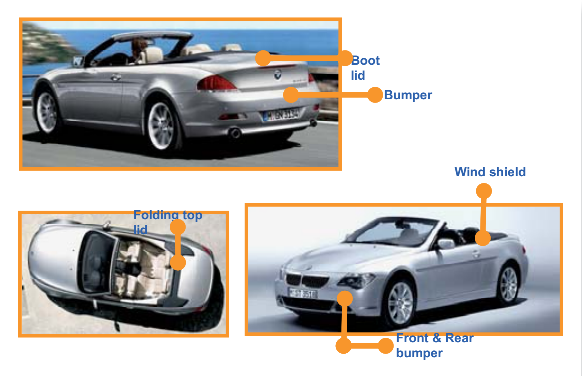


Fig. 3: possible placements in a convertible

Fig. 4: Integrated antenna system realized with self-adhesive copper strips



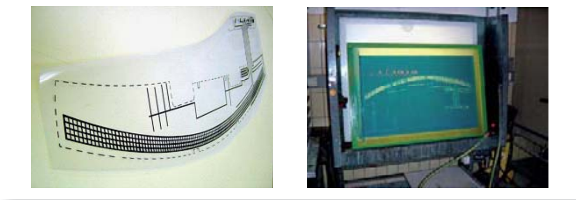

Fig. 5: Plotted film master and processing of screen printing form after contact exposure

different integration methods as inlaying, gluing, transferring and even over-molding (fig. 6) is possible. Every method got its own specific material combination e.g. the ink resin needs to withstand high temperatures of the molding process. The material compatibility is the most difficult but solvable issue.

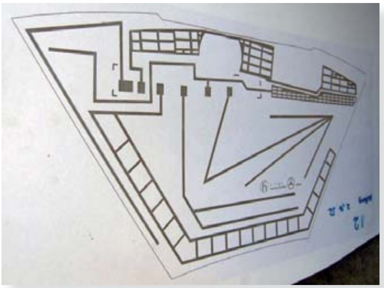

Fig. 6: Over-molding with thermoset material

## Inks

A very essential part of the research work was to specify the most appropriate inks.
The inks properties such as rheology and printability have been tested thoroughly using test patterns as shown in fig.7. The performance of the antenna relies very much on the silver content.

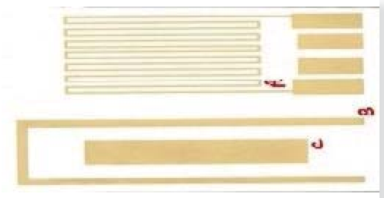

Fig. 7: Test layout for ink validation

On the other hand is the silver content the factor which has a great influence on the price. Also the particle geometry is important. Flakes or spheres are typically available. For the integration purpose the binder system is crucial, too. As well as having many advantages and attractiveness, the printed antenna must be competitive against the classical rod antenna. It could be shown that inks are most suitable whose silver content does not exceed a certain limit.

## Substrates

As mentioned earlier a very attractive alternative is complete over moulding. For this, the substrate properties are very important, too and must very well fit to the plastic material used for the body part (ABS, PC, PBT, PU or blends etc.). Quite large differences in their properties could be observed for varieties of films supplied by different vendors. Thus, only very few selected films are suitable for the over moulding process. For dimensional stability reasons only pre-shrunk films can be used. For better adhesion the films may be pretreated. After printing the drying parameters must be considered because an accurate thermal treatment is essential to enhance the conductivity and adhesion.

During the work the temperature settings, the heat treatment duration and the oven profiles have been optimized for each material combination.

## Material Testing

In order to be compatible to the requirements in the automotive industry the samples must pass extensive tests under extreme conditions. The antenna has to work in a very wide temperature range from -30° to 85°C. It has to stand dry and humid conditions and show good adhesion and unimpaired electrical performance even under heavy vibration.

The material compatibility for integrating the complete film can be tested best when keeping the samples for 4 days @ 85°C. As shown in fig.8 bubbles caused delamination during that test because obviously the PUR body part released gasses. A special selected material combination, shown on the left side of the test sample in fig. 8 performed much better.

In Fig. 9 an adhesion test between the ink and the substrates is shown where cross hatch cuts

are tried to peel apart with adhesive tapes. The tests showed that the adhesion to this type of substrate was good to excellent.
The most extreme temperature and climate test is the so called "Kataplasma-test". The test conditions are: keep in water at 70°C for 14 days and afterwards store 28 hours at minus 20°C. Although the antenna film sometimes shows minor peel off from the plastic materials at the edges (see fig. 10) all prototypes passed the test.

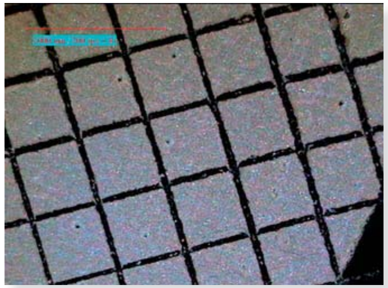
Fig. 9: Test sample after adhesion test

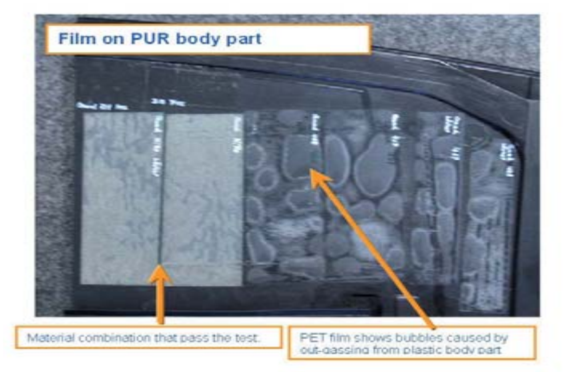

Fig. 8: Test samples after storing 4 days @ 85°C


Fig 10: Antenna film on polycarbonate body part after Kataplasma test

## Electric Performance Testing

The electrical performance was tested in the labs of Hirschmann. Hirschmann has a cabin totally free of electromagnetic waves. The printed antenna was tested against the standard rod as reference using different frequencies. The measurement results that are shown exemplarily for 88 to 108 MHz in fig.11 revealed that for FM the film antenna mostly are better than reference.

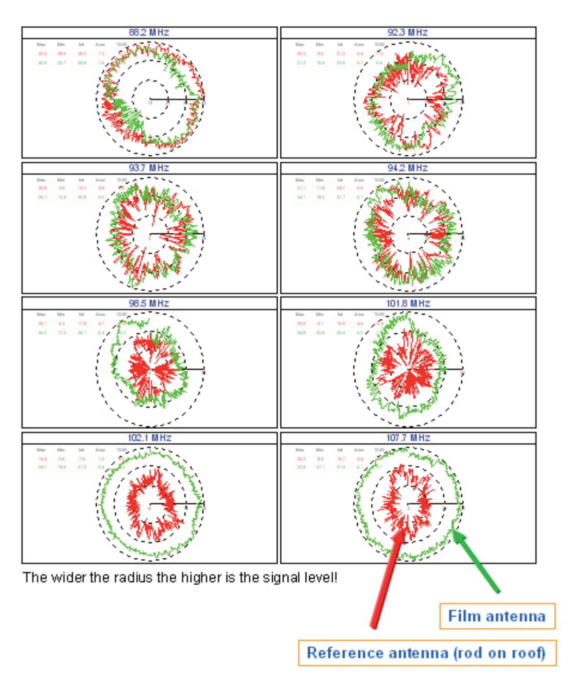

Fig. 11: Comparison of the FM-performance (88.2 – 107.7 MHz) between integrated film (green) and rod antenna (red)

## Applications

Fig.12 shows the first application with the printed antenna as a repetition part, an AGCO Fendt tractor. Since the first time that the integrated printed antennas were shown at the IAA fair, Frankfurt in September 2005 prototype studies have been made for Porsche, BMW, Daimler and VW. Today in series production are AGCO Fendt, Fendt Caravan and Volvo USA Truck. More start of series production will follow during 2008.

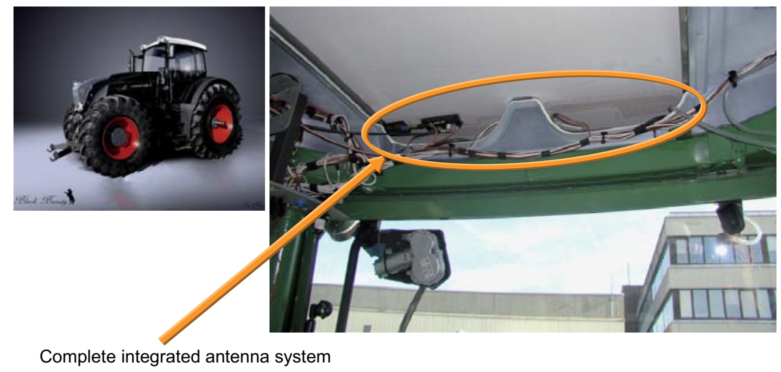

Fig. 12: First serial production of the developed integrated antenna system – AGCO Fendt X 900

## Summary

It could be shown during this project that printed antennas

- show superior performance
- are more flexible
- are adaptable to different geometries
- are cheaper (in most cases)

Especially the flexibility of the layout is the major advantage since more and more signals have to be received and/or transmitted in the future, some are

- bidirectional services,
- Bluetooth,
- Car2Car (safety related) or Car2Infrastructure communication

The nearest goal for future developments is to expand the technology to more possible applications. Therefore more prototypes are necessary. One great challenge is the application in more pronounced three-dimensional parts. Thus, the thermal forming after print or transfer will be investigated.

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