INTEGRATED MICROWAVE ANTENNA SYSTEMS IN MOBILE APPLICATIONS

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Introduction

For microwave antennas in vehicles as e.g. for mobile phone and satellite radio there is the great challenge to fulfil various requirements for multiple radio services at the same time. The antennas for these services have to be designed compatible to the skin of the car and can be especially hidden beneath plastic parts of the cars surface. In such a mobile environment we have to deal with multipath effects and interferences, to optimise the radiation pattern of the antennas with respect to the environment of the cars surface and to try to combine several radio services in one structure in order to minimize the number of positions for the integration of antenna and reception systems.

In this contribution an overview is given about the actual state of antenna concepts where especially compact multistandard antenna systems are compared, in which RF signal processing units and antennas for several services are integrated together at one common position at the vehicle. Further a method for the design and the automatic optimisation of the radiation pattern as well as the diversity efficiency of such combined antenna structures is shown.

Multistandard antenna systems with integrated RF signal processing

There are different possibilities for a signal processing close to the antenna. The most simple kind of integrated RF-signal processing is an antenna structure for multiple services connected with a frequency switch in order to make the different channels available at different ports at the antenna. These structures can be extended with an amplifier network where different amplifier concepts are applied to the different radio services. The integration of such antenna combinations together with its amplifier circuits in one narrow integration volume requires a high attention on coupling effects among the antennas and the circuitry [1] (example in fig.1). The common integration of multiple antennas and a connecting circuitry may also end up with a multifunctional antenna structure where each of the antennas is used for the same combination of services. In fig. 2 a multifunctional antenna structure is shown where four antenna elements are connected with each other via a phase shift and matching circuit. At the frequency bands of the different radio services where these elements are applied for, these elements act together like one variable frequency dependant antenna structure.

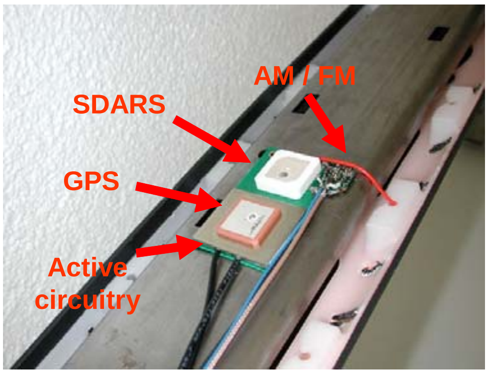

Fig. 1: Integrated multistandard antenna configuration inside a narrow integration volume with 7mm height

This antenna structure fulfils the different required radiation patterns at the frequency bands of the considered radio services. This is achieved via frequency dependant phases of the signals at the antenna elements which make the antenna elements act together performing different advantageous superpositions of their radiation patterns [2, 3].

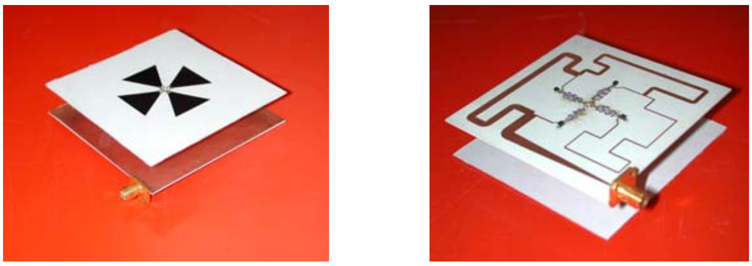

Fig. 2: Multifunctional antenna structure with integrated phase shift and matching circuit on bottom side

In a mobile environment as in a car we often have to deal with multipath effects and interferences. In order to be sure that there is always a sufficient reception there have to be used several antennas available for each service. In a diversity module the RF-signal processing is done in order to switch always on the antenna with the best actual reception. Since high efforts in wiring have to be prevented the diversity should be connected in close proximity to the antennas.

In fig. 3 an antenna configuration of rear screen antennas is shown together with the amplifier and diversity module in close proximity [4]. One step further is a remote tuner concept where the complete RF-tuner is connected directly to the antennas.

If the number of tuners is increased a phase diversity can also be realized where the different antenna signals are superposed in phase to each other. In contrast to the switched diversity there is an improvement also in those special cases where all antennas might have a bad reception, but where the signal levels are similar to each other. For the investigation and optimisation of such antenna diversity configurations the following design method is used.

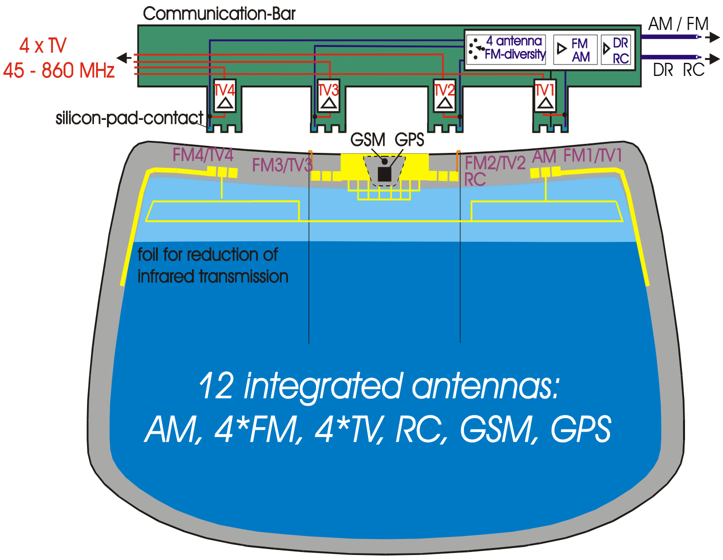

Fig. 3: Multifunctional integrated antenna configuration of rear screen antennas in connection with its amplifier and diversity module

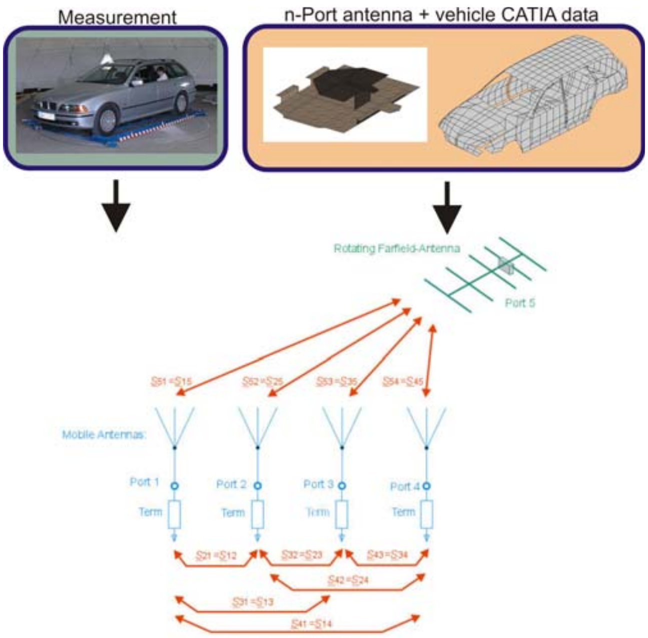

Fig. 4: Evaluation of the (n+1)-Scatter Matrix from measurements (left icon) or numerical calculations (right icon) with a 50-Ohm terminated antenna group (shown with $n = 4$).

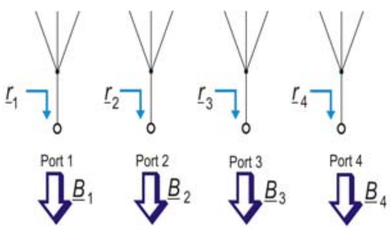

Fig. 5: Antennas with different loading than 50 Ohms

Method of design

In what follows, a method for the design and the automatic optimisation of the radiation pattern as well as of the diversity efficiency of such combined antenna structures is presented. In this method the environment of the antenna as well as possible interactions between antennas of different services are taken into account [5]. In this design method concepts for multipath suppression, antenna diversity and switched beam concepts can be investigated, optimizing the overall pattern of the complete system in dependence to the given driving scenario. In order to achieve this, the complex coupling between the n different antennas and a far-away illuminating antenna rotating around the car are either measured in a test range or calculated with the help of a numerical field solver (fig. 4). This results in a (n+1)x(n+1) scattering matrix $||\underline{S}||$, where the elements $\underline{S}_{op}$ with $o \neq p$ and both less than (n+1) represent the antenna coupling, $\underline{S}_{oo}$ the source impedance, and $\underline{S}_{o(n+1)} = \underline{S}_{(n+1)o}$ are the complex antenna patterns (derived from the far-away antenna) for the *o*-th antenna, always with 50-Ohm terminations.

Reactive Loading

For including the ***reactive*** loading of the antenna ports for optimization purposes e.g. the reflected signals from the ports also have to be taken in account (fig. 5). This leads to a matrix equation which has to be solved for the above scattering matrix $||\underline{S}||$ and the actual loads $\underline{r}_j$. The solution (eq.1) gives the four actual patterns in magnitude and phase of the reactive loaded antennas where $\underline{A}_{Send}$ is the wave amplitude of the incident wave and $\underline{r}_1$ to $\underline{r}_4$ are the reflection coefficients of the loads at port 1 to 4. From this equation the ratio of $\underline{B}/\ \underline{A}_{Send}$ which is the complex weighting factor $\underline{W}_i$ for the i^{th}

wave with a certain angle of incidence can be calculated. No other additional measurements or field calculations are needed!

$$-\underline{A}_{Sende} \cdot \begin{pmatrix} \underline{S}_{15} \\ \underline{S}_{25} \\ \underline{S}_{35} \\ \underline{S}_{45} \end{pmatrix} = \begin{pmatrix} \underline{r}_1 \cdot \underline{S}_{11} - 1 & \underline{r}_2 \cdot \underline{S}_{12} & \underline{r}_3 \cdot \underline{S}_{13} & \underline{r}_4 \cdot \underline{S}_{14} \\ \underline{r}_1 \cdot \underline{S}_{21} & \underline{r}_2 \cdot \underline{S}_{22} - 1 & \underline{r}_3 \cdot \underline{S}_{23} & \underline{r}_4 \cdot \underline{S}_{24} \\ \underline{r}_1 \cdot \underline{S}_{31} & \underline{r}_2 \cdot \underline{S}_{32} & \underline{r}_3 \cdot \underline{S}_{33} - 1 & \underline{r}_4 \cdot \underline{S}_{34} \\ \underline{r}_1 \cdot \underline{S}_{41} & \underline{r}_2 \cdot \underline{S}_{42} & \underline{r}_3 \cdot \underline{S}_{43} & \underline{r}_4 \cdot \underline{S}_{44} - 1 \end{pmatrix} \cdot \begin{pmatrix} \underline{B}_1 \\ \underline{B}_2 \\ \underline{B}_3 \\ \underline{B}_4 \end{pmatrix} \tag{1}$$

Multipath Simulation

As known, the Rayleigh- or the Rice distribution in a mobile environment is a result of the superposition of direct (incident) wave and random scatterers for signal and interferer as well (see fig. 6). This, of course can also be simulated.

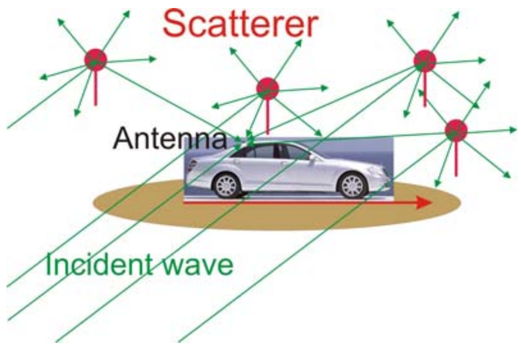

Fig. 6: Simulation of the multipath disturbed field

Port voltages

The simulation uses a number of q signal waves with random amplitude, phase and incident azimuth angle. The port voltages are found from the superposition of the q incident and the load dependent re-radiated (reflected) waves, weighted under consideration of the angle of incidence by the complex antenna heights. With Z_0 as characteristic system impedance and the complex weighting factor $\underline{W}_i$ from eq.1 this procedure gives the resulting voltage from all q waves having the complex amplitude $\underline{A}_i$:

$$\underline{U}_{Port} = (1 + \underline{r}_{Port}) \cdot \sqrt{Z_0} \cdot \sum_{i=1}^{q} (\underline{W}_i \cdot \underline{A}_i) \tag{2}$$

Results are shown in in a linear representation in fig.7. The same kind of super-position has to be done for the interfering waves. If the signal voltage drops below the interferer voltage a fault counter is incremented. The calculations have to be carried out in sub-wavelength distances along the whole route. While the diversity gain depends on the actual *S/N* ratio the ficticious number of independent additional antennas keeps constant. If during a test drive with z samples the single antenna counts s and the diversity system counts d dropouts the number n_a of independent additional antennas is

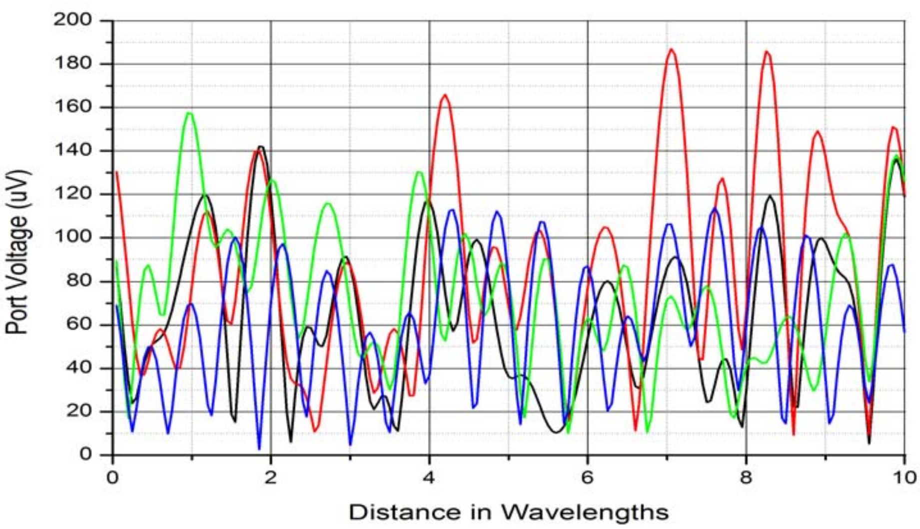

Fig. 7: Simulated port voltages with a 4-antenna system. The interferences lead to standing waves with deep fadings in roughly quarter wavelength distances.

$$n_a = \frac{\log(d) - \log(s)}{\log(z) - \log(d)} \tag{3}$$

Of course, the results of a real-life test drive or of such a simulation depend strongly on the environmental conditions. In order to get acceptable statistical values the number of test drives in different environments has to be typically greater than 20.

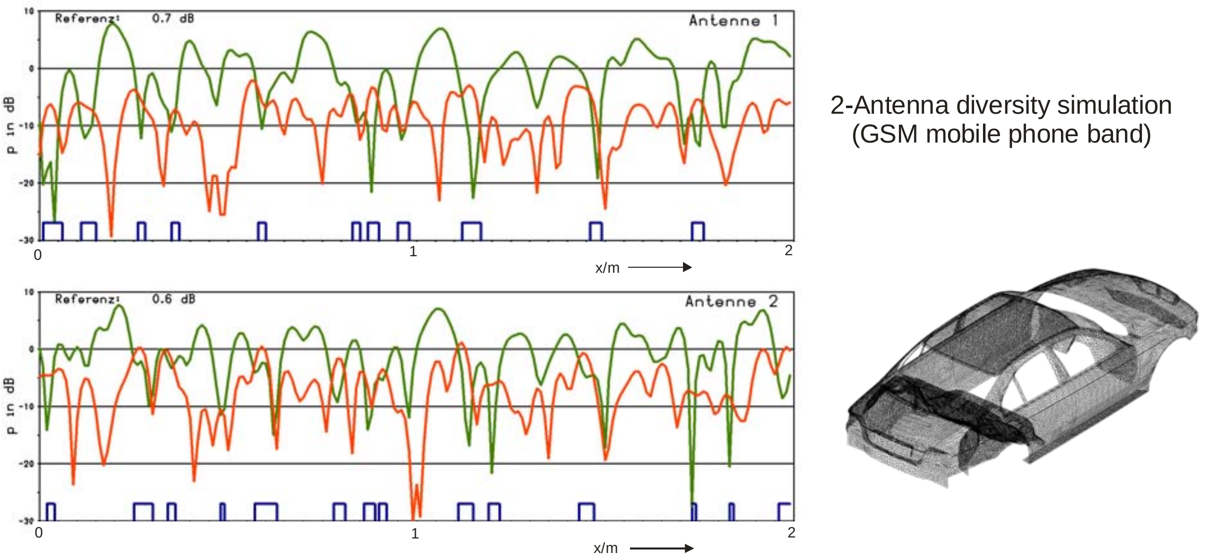

Fig. 8: Multipath scenario on base of numerical simulation of two antennas and car

Fig. 8 shows as an example the reception with a 2-antenna system where the green graph represents the signal strength and the red graph the interferer. The markers at the bottom line indicate the intervals where the interferer is stronger than the signal. Fig. 9 shows as a comparison the measured results for the signal strength in a GSM mobile phone application using now four antennas integrated into the car. The results show a good overall agreement of the antenna behaviour in the multipath scenario.

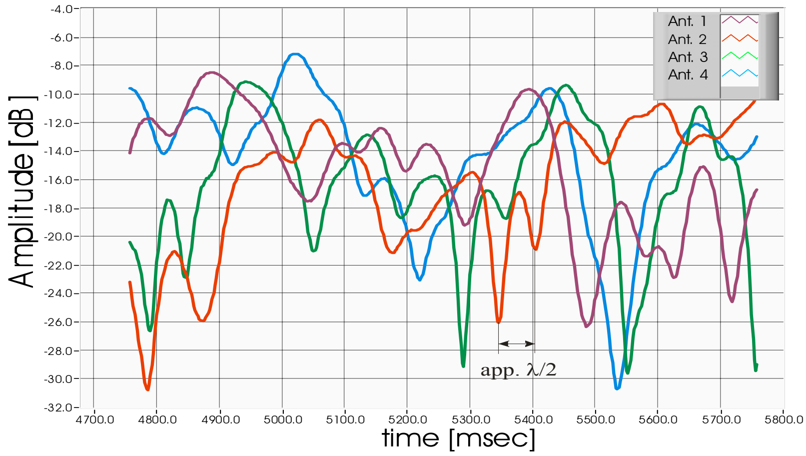

Fig. 9: Measured multipath scenario in real environment

Literature

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