ADVANCES IN FM CARRADIO RECEPTION

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1. Minimum required signal level for FM reception

Up to now no minimum required signal level for mobile FM broadcast reception has been defined. Due to the random character of the received signal in fig.1 its relevant level can only be determined by means of statistical characteristics such as the exceeding probability distribution of the instantaneous logarithmic signal amplitude at the input of the carradio (see fig.2). This curve can be characterised by the median voltage level V_m, which is exceeded in 50% of the time. Normally the steepness of the slope is characterised by the level difference "b" between the 10 % and the 90% points, which in a Rayleigh field is found to be app. 13 dB. A working group of the German Society of Car Producers has defined minimum required signal levels under various receiving conditions. V_m= 24 dB μV has been found for FM reception in urban areas and V_m = 13 dB μV in non urban and flat areas of reception. These low signal level requirements are only valid in areas where no multipath distortions due to great differences in delay time (τ = 3 μs) is observed /1/.

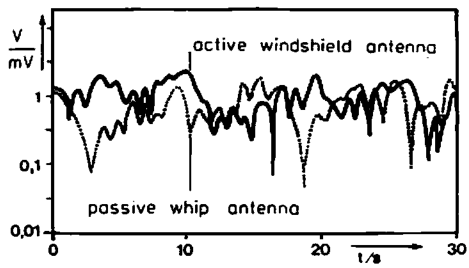


Fig.1: Rf-level versus time

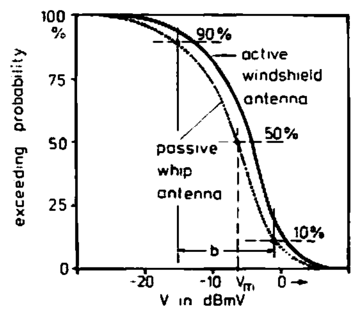


Fig.2: exceeding probability of rf-level

2. Antenna characteristics

Very often the main specification relevant to describe the performance of a FM car antenna is considered to be the directional diagram as to be seen in fig. 3. However the artificial situation of only one wave being incident at the location of reception, which with pattern measurements is assumed, does not meet the physical conditions of FM carradio reception in practice. In fact at any location of reception there is a multitude of coherent waves of complex amplitudes $\underline{A}_1 \ldots \underline{A}_w$ incident from various directions 1...w in azimuth φ and elevation Θ. With $\underline{C}(\varphi, \Theta)$ representing the complex antenna factor and $\underline{A}_\nu \, \underline{C}(\varphi_\nu, \Theta_\nu)$ representing the contribution of wave ν to the complex voltage amplitude at the receiver input it becomes obvious that the total complex amplitude at the receiver in a standing car reads as:

$$\underline{V} = \sum_{\nu=1}^{w} \underline{A}_\nu \cdot \underline{C}(\varphi_\nu, \Theta_\nu) \quad ,$$

and can cancel out even if the diagram would be omnidirectional ($\underline{C}(\varphi,\Theta) \equiv 1$). In a driven car the set of complex wave amplitudes varies very rapidly versus the time in magnitude, phase, angle of incidence and number of waves to be considered, so that the receiver input voltage reads as:

$$\underline{V}(t) = \sum_{\nu=1}^{w(t)} \underline{A}_\nu(t)\cdot\underline{C}(\varphi_\nu(t),\theta_\nu(t))$$ and varies within a wide range

as to be seen in fig.1. The validity of these considerations can be seen from fig.4, where the amplitudes of the instantaneous set of waves are plotted versus their angles of incidence. These angles have been found by measuring the doppler frequency shift f_D of an unmodulated and highly frequency stabilized FM broadcasting carrier which for this purpose has been radiated by the Bavarian Broadcasting Corporation with a power of 100kW erp. f_D is found from:

$f_D = f_c \cdot v/c_0 \cdot \cos\varphi$; f_c: Carrier frequ.; v: car speed; c_0: velocity of light.

With V(t) being of random character it is obvious that only little can be predicted with respect to a definition of a desirable antenna factor representing the directional diagram. In contrast hereto the exceeding probability distribution has been found to be a reliable and easy to measure means to characterize the antenna performance.

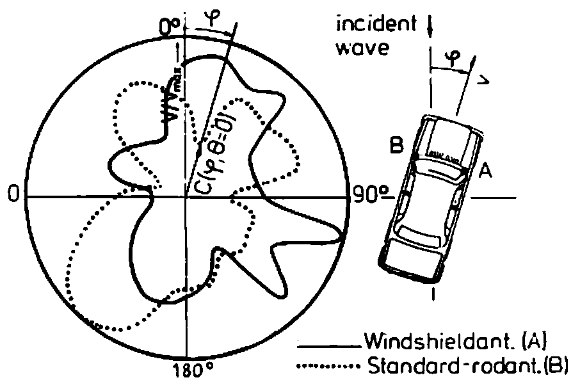


Fig.3:Hor.diagram with single wave.

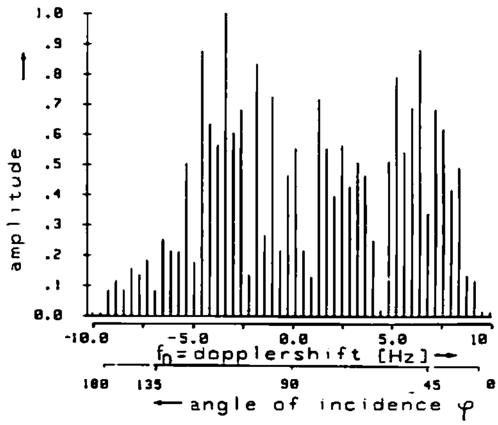


Fig.4: Wave amplitudes versus angle

3. Active windshield antennas as an original equipment

Windshield antennas are often blamed of being "more directive". Fig.3 shows that there is no criterion that the diagram of antenna B should be preferred to that of antenna A. In fact the exceeding probability distribution with an efficient windshield antenna is of the same profile as obtained with a rod antenna. Fig.5 presents an active FM-AM-antenna which is implemented in the series of all types of Porsche cars. The design is optimized with respect to the reception of horizontally, vertically, and circularly polarized FM-waves and is adapted to the individual car bodies by appropriate choice of d and l of the conductor. The exceeding probability distribution of this antenna is compared to the whip in fig.2.

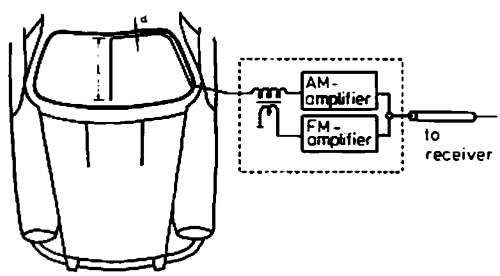


Fig.5: FM-AM windshieldant.

4. Multipath distortions and other FM distortions

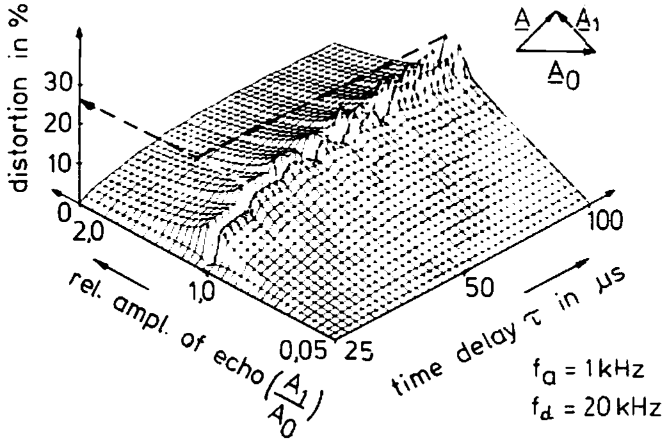


Fig. 6: Multipath distortions.

It is well known that multipath reception disturbs the modulation contents and harmonics are generated as a function of the difference of propagation time τ between a wave of amplitude A_0 and an echowave of amplitude A_1 if only two waves are existent. The diagram in fig.6 presents the distortion in the audio-channel as a function of τ and A_1/A_0. Due to the FM-modulation and to τ the speed of angles of the two complex vectors $\underline{A}_1$ and $\underline{A}_0$ are different, the erraneous frequency

If $\emptyset(t)$ represents the modulation signal deviation $\dot{\beta}(t)$ reads as /2/:

$$\dot{\beta}(t) = \frac{\sum_{i=1}^{w} [(\emptyset(t-\tau_i) - \emptyset(t))(A_0 A_i \cos\gamma_i(t) + \sigma_i(t))]}{A_0^2 + \sum_{i=1}^{w} (A_i^2 + A_0 A_i \cos\gamma_i(t) + \sigma_i(t))}$$

$$\gamma_i(t) = -\omega_T \tau_i + \emptyset(t-\tau_i) - \emptyset(t),$$

$$\sigma_i(t) = 2 \cdot \sum_{j=i+1}^{w} A_i A_j \cos(\omega_T(\tau_j - \tau_i) + \emptyset(t-\tau_i) - (t-\tau_j)).$$

and contains pulses of frequency deviation forming a criterion for the signal distortion at the output of the FM-demodulator. On this basis a distortion detector has been developed indicating also distortions as a result of noise due to multipath distortions with low difference in delay time, co-and neighbour channel interference, nonlinear distortions, and ignition noise as well. Fig.7 shows the distortion level versus the driving distance measured with this detector and the antennas on the car in fig.5. The median distortion level with the windshield antenna was app. 10% less than with the rod. Obviously the peaks of distortions exceeding an audible threshold with the two antennas are only very little correlated. Therefore antenna diversity provides a substantial improvement of signal quality to the system.

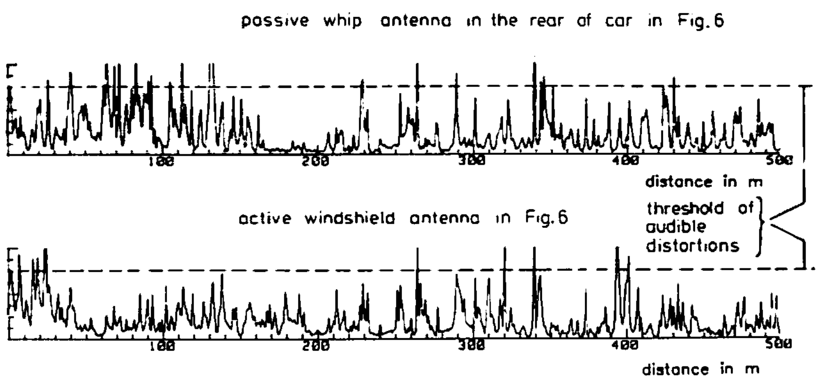


Fig.7: Distortion level versus driving distance at the output of the fast detecting distortion indicator.

5. Antenna diversity with fast indicating distortion detector

In the following receiving results are described which have been obtained by means of the diversity system in fig.8 containing a newly developed extremely fast indicating distortion detector of app. 25 µs detection time. This renders the application of an antenna selector, which sequentially chooses the best antenna signal among a variety of N antennas with only one single tuner. Measurements have shown that with increasing number N of antennas

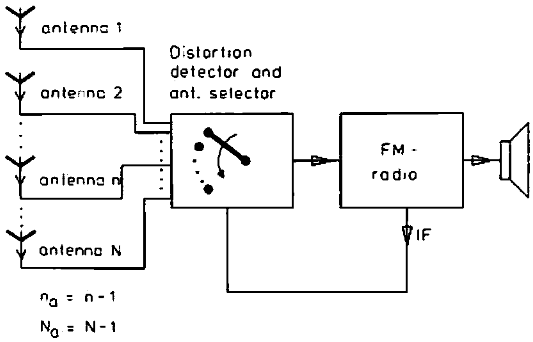


Fig.8: Ant.div. with fast detector;

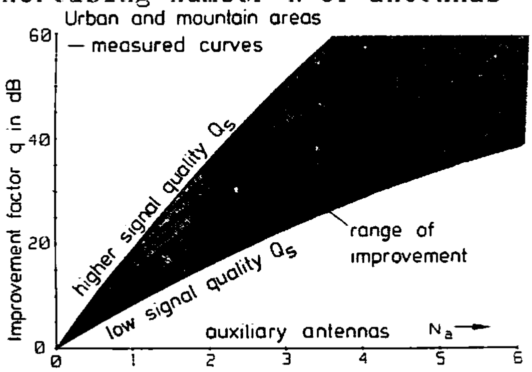
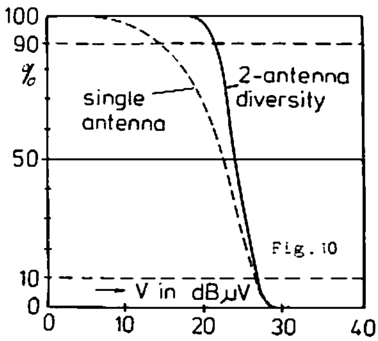


Fig.9: Improvem. with ant.div.

applied the fraction P_d of the time in which the threshold of distortions in fig.7 is exceeded is reduced exponentially and that this improvement is increased with the signal quality Qs. This can be shown from the following assessment, which in a first approach is made under the assumption of equal distortion probabilities $P_1 = P_2 = \ldots P_N = P$ and negligible correlation of the distortions found at the antennas 1...N. Qs = 20 log (1/P) may be considered as the signal quality with the single antenna system. Hence the probability of a distortion with the N-antenna diversity system with Na=N-1 auxiliary antennas is found to be the joint probability $P_d = P^N$. If the improvement factor q is defined as P/P_d its logarithmic value $q_{dB} = 20 \log q$ reads as $q_{dB} = Na \cdot Qs$. The shaded range in fig.9 represents measured curves of the improvement factor versus the number Na of auxiliary antennas under various receiving conditions. With higher numbers of Na the correlation between the antenna signals can not be neglected, which causes the curves to bend. Fig.10 shows impressively the exceeding probability distribution of an antenna diversity signal. Since the diversity system constantly selects the antenna with the better signal the level at the receiver varies only within a very small range and the deep notches in the signal, during which most of the distortions well known with FM-carradio reception are generated, are less likely.



References:

/1/ Lindenmeier, Hopf.: Investigation for determining the minimum signal level for VHF.. Rundfunktechn. Mitteilungen, Jg.28(1984), H.2, p74-81

/2/ Lindenmeier, Manner, Reiter: Distortions in FM carradio ... Proc. URSI Comm. F 83 Symp., (ESA SP-194), p.37-44.