Antenna Design for Mobile Radio Systems

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Summary. The paper examines the role of the choice and siting of antennas on the performance and spectral efficiency of mobile radio systems, and outlines techniques for the design of base station antennas with a variety of different azimuth patterns.

1. Introduction

The re-engineering of mobile radio systems is providing improved facilities to users and has presented an opportunity to obtain greater efficiency in the use of the radio spectrum.

The selection of radio site locations, together with the choice of suitable antennas, are vital steps in the design of a radio system which is capable of meeting the user's communications objectives.

> *A note on reciprocity*. In order to avoid tedious repetition, most of the effects referred to below are described from the point of view of one direction of transmission only; in most cases there is a similar or related effect which exists with the reverse direction of transmission, but this is not always spelled out in detail. In those cases where the reciprocal effect does not appear to be a problem, it is worth some thought as to why this is so.

2. Planning the service area

2.1 Co-channel interference

One of the main obstacles to achieving high spectral efficiency in any radio system is highlighted in Figure 1. Over level terrain, with an antenna elevation of, say 30m, a satisfactory signal capable of providing a high-grade service is laid down over a radius r. A minimum signal/interference ratio is needed for the service, so the frequency cannot be reused over an area of radius R. It is obvious that the annular zone lying between r and R has a very much larger area than the served area; in this larger area the base station may lay down an inadequate signal to provide a reliable service, but it lays down enough signal to preclude others from using the same frequency.

The carrier/interference level which is necessary for proper operation varies according to the system which is in use (voice, data, vocoded speech &c.) and to make matters worse the required protection ratio must be maintained during most temporal variations of propagation conditions - this problem has most effect at lower frequencies. Protection for 99% of the time will result in a total of 4 lost days in a typical year, but as the protected time is increased the total number of systems which can be accommodated in the available spectrum will diminish.

2.2 Using the terrain

The lie of the land may be used to reduce the spoiling effect by helping to control the extent to which signals are spilled out of the service area. It is clear that as terrain screening will reduce the spillage of signals out of the service area, we will at the same time reduce the extent to which the base station is exposed to unwanted reception of signals from outside the service area. The logic of this process results in siting stations on comparatively low ground, firing towards hills, using antennas with some directivity.

It is also worth noting the major advantage in spectrum utilization - outside the antenna engineer's remit - which comes from designing systems which are robust enough to tolerate a low carrier/interference ratio, and there is a useful benefit if degradation in the presence of high interference levels is graceful, so that in times of poor c/i ratio the data rate is reduced but the system does not fail completely.

3. The mobile antenna

The efficiency of spectral utilization is reduced when mobile antennas are poorly sited on vehicles as this results in distorted radiation patterns. As the vehicle orientation must be assumed to be random with respect to the direction of the base station, the effective communication range for a given base station erp is reduced - ie r falls while R is unaffected or may even grow! Even if the azimuth patterns are not distorted, the result of elevation pattern distortion may be that the antenna has a low effective gain in the horizontal direction. The result of the poor performance of mobile antennas is that the system requires a higher base station erp than should be necessary, or that the area which the user perceives as being adequately served is diminished.

The recently published JRC Mobile Antenna Performance Test Report (JRC, Spring 1991) illustrates the extremely wide differences in gain and radiation patterns which are obtained by simply choosing alternative antenna types and mounting positions.

There are no magic solutions, but an awareness of the improvements which are possible should allow the mobile radio community to make useful progress and to avoid mounting arrangements and antenna designs which needlessly compromise performance.

4. The base station antenna

For mobile radio applications in the VHF and UHF bands, the main antenna parameters which can be varied to suit the application are the azimuth radiation pattern and array gain. The typical vertical aperture of a base station antenna does not allow a significant degree of control of the elevation pattern as in most circumstances it is too broad to provide useful discrimination between the nearer parts of the served area and the remote edge: for a base station with an effective antenna elevation of 50m, a point 3km distant lies at an elevation angle of only -3 degrees. Elevation pattern control can contribute usefully at frequencies of 800MHz and above, where larger antenna apertures (with small vertical beamwidths) are more common.

In order to minimise co-channel interference the erp radiated from a base station antenna must be as low as possible in all directions of azimuth, so the most efficient antenna will be one whose pattern most closely matches the ideal shape needed.

4.1 Azimuth pattern ripple

The most difficult antenna to design is one with a smooth omnidirectional pattern. Only a few types of antenna have such a pattern even in free space, and in practice the pattern can only be obtained from a single top-mounted location (which also suffers the largest incidence of lightning strikes.) Side mounting gives rise to major pattern irregularities which have usually been covered by over-design; the resulting service is degraded unless the irregularities are avoided, or are understood and put to good use. Fortunately, very few base stations need to serve an exactly circular area, so minor pattern disturbances can usually be accommodated.

4.1.1 Predicting pattern disturbances

There are a number of available methods for predicting the interaction between antenna elements and their supporting structures.

The azimuth patterns of antennas mounted on solid obstacles, or on lattice structures with small cross sections (typically less than about a wavelength in diameter) which can be approximated as solid obstacles, can be calculated analytically using a suitable program for a simple PC.

Large lattice structures cannot be simplified as regular diffracting obstacles and it becomes necessary to model their individual members. NEC (Numerical Electromagnetic code) or MININEC can be used for more complex problems, but as the size and complexity of the structure increases, the complexity of the input data (and the time taken to generate and check it) and the size of the computational task increase. It is often necessary to approximate to obtain an accessible solution, but such approximations must be made with sufficient understanding of both the physics of the problem and an understanding of the solution technique employed by the computer program.

Once the radiation pattern of the real antenna - positioned on its mounting structure - has been obtained, the result can be used in the coverage prediction routine.

4.1.2 Obtaining smooth patterns

Tolerably circular azimuth patterns can be obtained on structures with side dimensions up to around 1.5 wavelengths, using four panels firing radially outwards, and this type of antenna, originally used for radio and TV broadcasting, is now seen more often at mobile radio base stations. The patterns and impedance of individual panels are determined by the type and position of the radiating element used, and its location with respect to the rear reflecting screen. As long as the design is sound, the performance of the individual panel is affected very little by the structure behind it, or by coupling to other panels alongside. Complex patterns (magnitude and phase) measured on a test range are entered into array design program and the resulting predictions can be used with a fair degree of confidence. Pitfalls do arise when elements are not co-phased, as any imperfect VSWR at the input to the panels will result in incorrect power division in the array. Panels can be solidly constructed and their small coupling to the supporting structure allows low levels of passive intermodulation products (PIMPs) to be obtained and maintained over the life of the system.

As the dimensions of the supporting structure increase, problems become more difficult to manage and deep nulls appear in the azimuth pattern. Some relief can be obtained by adopting even more complex array designs - at UHF TV frequencies broadcasters have adopted arrays with six or eight panels around a 2-m mast, but even these arrays have pattern ripples of around 6dB.

The problem is seen in Figure 2. Over the arc 'A' signal is received dominantly from a single source, the others are screened by the structure and also fire in other directions. Directly off each corner of the structure, exactly equal signals are received from two adjacent sources and a typical grating lobe structure is developed, characteristic of the electrical spacing between the sources. We may note that introducing phase shifts between the sources will simply have the result of slewing the grating lobes round - they remain just as deep.

An approach to the problem which may sometimes be useful is to abandon the idea of obtaining full 360- degree coverage and opt for solid coverage over an arc of around 270 degrees; the remaining 90 degrees is unserved, or served with some remaining unavoidable nulls placed where they do least harm to the required coverage. Perhaps a second channel could be used to cover the remaining arc and the holes in the antenna patterns used as an opportunity for improving the pattern of frequency re-use.

4.2 Forming intentional Nulls

Nulls may be needed to provide specific protection to other users of the channel, or they may be used simply to avoid over illumination of areas where service is not required (and from which any received signals would in any case simply represent unwanted interference). Several different methods are available for generating wanted nulls; they have different merits and shortcomings and the choice between them may rest on these differences.

a. **Simple omnidirectional antennas mounted off the supporting structure.** We are now using structural blockage to advantage; the null obtained will be of moderate depth (6 -15dB) and will be stable over a fairly wide frequency band. It can be predicted with fair accuracy for small/medium structures and will remain stable over the life of the station. As parts of the structure are strongly illuminated, there will be fairly high potential for the generation of PIMPs (the rusty bolt effect).

b. Small arrays of simple elements. Results will be predictable if care is taken to avoid illuminating the structure. If null performance is critical, it is worth making sure that the antenna supplier provides evidence of the performance of the antenna. A well designed double-dipole cardioid array will provide nulls 25 - 30dB deep, while an apparently similar one which is not correctly fed struggles to provide 10dB. Take time to check the performance of the installation after it has been completed, to avoid the possibility that anything has been incorrectly assembled.

c. Subtractive methods. Narrow nulls can be generated within broad lobes by mounting a narrow beamwidth antenna fired towards the wanted null direction and exciting it in antiphase with the main antenna. This technique is capable of generating some useful and unusual patterns, but it suffers the disadvantage that slight degradation of the antennas will change the null depth. The design of these systems must be carried out rigorously and it is essential that the configuration is installed exactly as it was designed. The exact mounting coordinates of each element of the array, and the amplitude and phases of the currents exciting them must all be controlled with sufficient accuracy to assure that the correct pattern is achieved. Commissioning and regular maintenance checks must be made to ensure that the null has been generated to the required depth.

5. Conclusion

The last ten years have seen a major change in the approach to antennas in mobile radio systems. There are still areas in which the exploitation of the best available techniques can contribute to the quality of service available to users and can increase the utilization of the available spectrum. The increasing availability of good computer tools is allowing the benefits of these improvements to be more widely enjoyed.

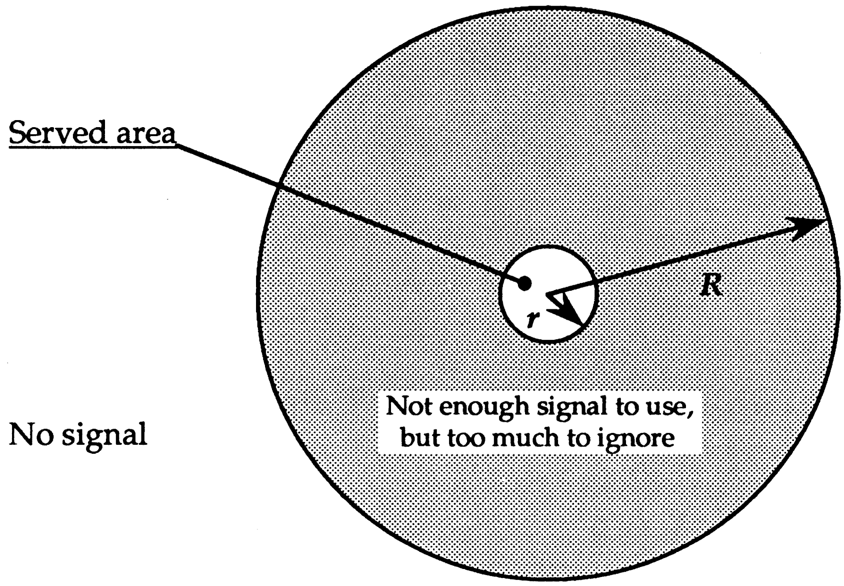

Figure 1. Served radius r with surrounding unserved radius R

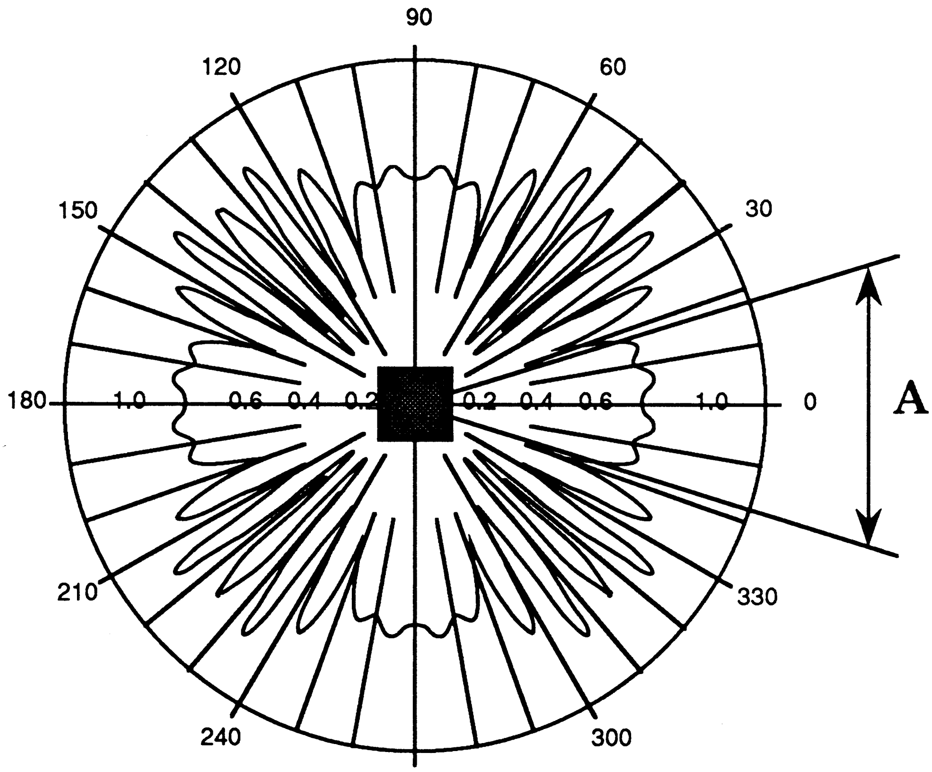

Figure 2. A typical azimuth pattern for sources over-spaced around a large structure