Technical Note

Options for shaping the elevation radiation pattern of base station antennas

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Summary

This short paper describes the possibilities and practical applications of the shaping of the Elevation radiation pattern of mobile radio base station antennas. The functions and method of achievement of upper side lobe suppression, beamtilt and null fill are examined in detail.

1 The unshaped pattern

A base station antenna usually comprises a number of identical elements mounted in a vertical line. If these elements are excited with currents of uniform amplitude and phase the result is a characteristic unshaped elevation pattern. This is shown in Figure 1. A main lobe of 3-dB beamwidth θ° is directed in the horizontal plane, and symmetrical patterns of sidelobes and nulls appear both above and below the main beam.

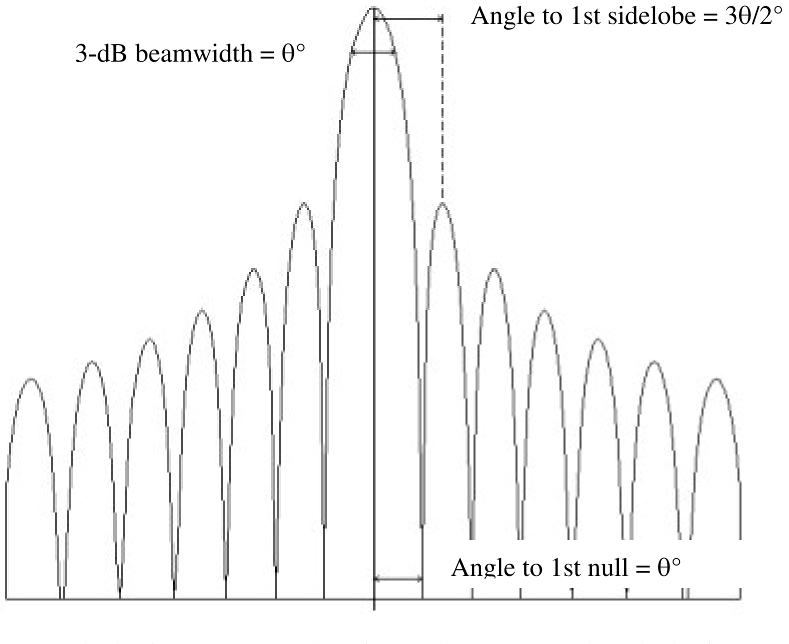

Figure 1: Elevation radiation pattern of an array of elements with equal co-phased currents, showing the basic angular relationships which apply to any broadside array with equal or nearly equal currents.

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The sidelobes appear at angles of $1.5\theta^\circ$ and the first null is at θ°. As all the elements of the antenna are excited in phase, the field from each element will add constructively in the direction of the main beam. In this situation the directivity (and gain) of the antenna has their maximum values.

2 Radio and TV broadcasting

For many years, arrays of 4 or 8 elements with unshaped elevation radiation patterns were used as base station antennas. In the broadcasting industry, where a single station is expected to serve a very large area, arrays of 16 or even 24 elements are not uncommon. These arrays are typically mounted on structures with heights of 300m (1000ft), often situated on elevated hilltop sites. In such a situation the use of an unshaped elevation pattern as two obvious drawbacks: the main beam is directed above all the users, and nulls below the main beam will cause significant areas of inadequate signal. It has become normal practice to tilt the main beam downwards, typically by about half the 3-dB beamwidth, and to fill the nulls within 10° - 15° below the main beam by the choice of appropriate element currents. An ideal shape for the lower part of the radiation pattern approximates a cosecant law, but in practice the signal level typically is allowed to fall 6 - 12dB short of this in the nulls.

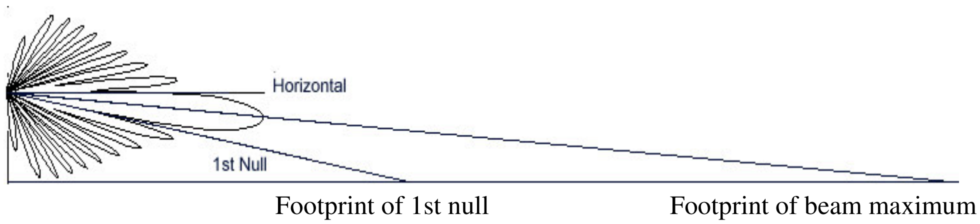

Figure 2: An installed elevated array showing the distances to significant points on the elevation pattern of the array (flat earth simplification).

3 Base station antennas

Although a number of features of the mobile base station environment are similar to those for broadcasters, there are also significant differences which affect the way in which elevation patterns must be shaped.

3.1 Beamtilt

In order to maximise the capacity provided by a mobile network, the area of coverage of individual base stations is carefully controlled. Only during system roll-out, or in sparsely populated rural areas, is maximum range of coverage the most important consideration. More typically the spacing between base stations is chosen to provide adequate capacity and the coverage of individual base stations is deliberately reduced to provide optimum frequency re-use. If coverage is controlled simply by reducing the transmitted power, poor service is provided inside buildings or in shadowed areas. The solution usually adopted is to employ beamtilt, deliberately directing the main beam of the of base station antenna downwards, increasing the field strength within the coverage area and at the same time reducing signals radiated towards the adjacent cells.

3.2 Sidelobe suppression

In rolling terrain or city centres, some areas of adjacent cells may lie above the horizontal plane when seen from a base station antenna mounted on a short structure in a low-lying location. To provide optimum frequency re-use in this situation, the planner now wishes to ensure that the base station antenna radiates the minimum possible signal over some range of angles above the main lobe. The range of angles of interest may extend as far as the first upper sidelobe of the unshaped beam, or perhaps even further.

By the suitable choice of currents in the elements of an array, the antenna designer can reduce the level of the upper side lobes. The new current distribution will result in a slight broadening of the main beam and a small reduction in the directivity (and gain) of the antenna. The reduction of directivity will be larger if the level of suppression is increased, particularly when suppressing sidelobes close to the main beam. Sidelobe suppression can be achieved by varying either the amplitudes or the phases of the radiating currents, or both. The gain of the antenna is reduced because the array has non-uniform current amplitudes (usually tapering towards the ends), and the fields no longer add to the maximum possible value because even at beam maximum some phase shifts remain.

3.3 Null fill

We have noted above that broadcasters introduced null fill (more than 50 years ago) to avoid significant areas of reduced field strength in the service area. While the same logic can be applied to the mobile radio environment there is a very significant difference in the practical situation. These differences relate both to the geometry of the two situations and also to the frequency bandwidths and sensitivities of the modulation systems to frequency distortion.

Figure 2 shows a typical broadcast environment in which a 16-wavelength antenna is mounted on a 300m mast and has a beamtilt of 1.6° (half the 3dB beamwidth). In this example the first null lies 1.6° below the main beam and is projected onto the ground at a distance of 5.4km (3.3 miles) from the antenna. In the case of an 8-wavelength base station antenna mounted 20m above ground level and again tilted by half a beamwidth, the first null falls only 175m (0.1 mile) from the site. It is worth noting that even in a deep null the signal level is unlikely to fall below –30dB relative to the main beam. Even if we apply only a simple square-law field strength/distance relationship, the field strength in this area would be the same as that five kilometres from the antenna with no beamtilt.

In addition to these considerations, the broadcaster has (until recently) been transmitting analogue signals which have been very intolerant of frequency-dependent amplitude or phase distortion (particularly in the case of colour

TV). Simple digital modulation schemes are much more robust, so problems of movement the exact position of the null as a function of frequency are of much less concern to the mobile operator.

A second result of the very different geometries of the two scenarios is that, because of the larger angles from the main beam in the mobile radio situation, there is a much higher probability that signal from the area brightly illuminated by the first side lobes will be scattered forward into the area less brightly illuminated by the first null.

As a result of these very different considerations null fill has been differently applied in the two situations and a review of network operators' specifications and the catalogues of many base station antenna manufacturers shows that many users regard null fill as not really necessary, the preference being to obtain the last few tenths of a dB of gain.

If an antenna is downtilted by one half of the 3-dB beamwidth the ratio of the distance of the footprint of the main-beam maximum to that of the first sidelobe is close to 3; applying a 3.5 power law, this suggests that providing the same field strength at the two points will require null fill at -17dB. The situation relating to adjacent cells is examined in paragraph 3.4.

It is interesting to note that in most countries it is now required that field strengths must be reduced to specified safe levels at locations close to the antenna which can be accessed by people (in particular, by the general public). The specification of lower sidelobe suppression may become more common for this reason.

3.4 Beam tilt

For some years mobile radio operators have used beamtilt as an essential tool in achieving a higher level of frequency re-use. As we have noted, limiting the coverage of the base station simply by reducing the effective radiated power has the result of reducing the field strengths throughout the cell. This will have the undesirable effects of reducing in-building coverage and the coverage of shadowed areas. By contrast, if the main beam of the base station antenna is tilted downwards the radiated field outside the cell is reduced while the signal within much of the cell area is increased (it is reduced only in an area near the cell boundary). This effect may be compared with that of dipping the headlights of a car, creating a much sharper edge to the illuminated area.

3.5 Beam tilt with null fill

The use of beam tilt is frequently necessary to prevent an adjacent cell illuminating a coverage minimum within an adjacent cell. This situation will lead to unwanted hand-offs or soft handoffs. Even if the beam of adjacent cells is arranged so the footprint of the adjacent cell coincides with the footprint of the maximum of the home cell, any area of minimum caused by the first null of the home cell will lie above the main beam of the neighbouring cell, at around -4dB as long as the adjacent cell has the same beam tilt. (The path length is larger in the ratio 5:1 (see Figure 3), so the path loss is about 24dB larger and the total protection ratio is 28dB.) In practice this is probably an

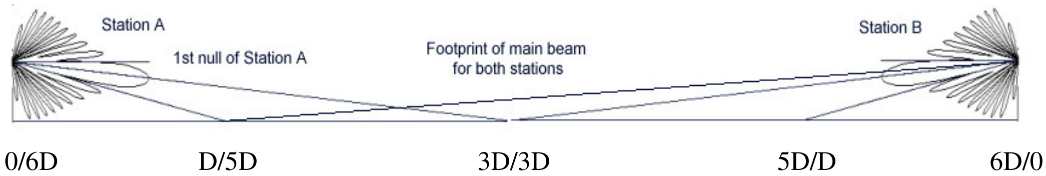

Figure 3: Two adjacent stations, showing distances of relevant points from both stations (Distance from A/Distance from B). This is an extreme case where the footprints of the beam maxima coincide. Larger distances between stations will make the null fill requirement less stringent.

unrealistically close spacing between the stations, so the ratio of the distances at the first null is too small; the null fill limit could be lower than this. It is interesting to see that the effect of the beamtilt of Station B is not very significant in this calculation, as most of the field strength reduction comes from path loss (24dB) and not antenna beam shape (4dB).

These calculations suggest that the null fill level can be between 17dB and perhaps 30dB below the main beam. These calculations would not apply to very closely-spaced base stations, where the propagation power law may more nearly approach 2, but in such conditions it might be expected that much larger beamtilt angles would be applied to reduce coverage overlap.

The introduction of antennas with remotely controlled electrical tilt is providing a new and potentially dynamic tool with which operators can control the footprint of a base station antenna. The use of this technique may be expected to rise with the introduction of 3G W-CDMA systems where unwanted overlap between cells rapidly reduces the capacity available on the network.

4 *Practical implementation*

Upper side lobe suppression and null fill are both provided by the choice of an appropriate illumination function for the antenna. In most designs both the amplitudes and phases of the radiating currents are adjusted to produce the desired pattern shape. As we have seen the shaping results in a broadening of the main beam and a reduction in the directivity and gain of the antenna. The larger the extent of beam shaping, whether the suppression of upper sidelobes or the filling off the lower nulls, the larger the consequent reduction in gain.

A very high standard of pattern shaping can be usually be achieved in an antenna covering a single frequency band at a fixed beamtilt, especially in the case of a vertically-polarised antenna where inter-element coupling is small. In this environment the impedance match of each element can easily be well optimised, and inter-element coupling is small and fixed. The design challenge increases in dual-polar antennas where inter-element coupling is significantly greater, and further increases in dual-band antennas where larger design compromises are made to accommodate elements for different frequency bands in a constricted space. When design compromises are necessary, an order of priority must be assigned to achieving the required functional parameters for the antenna. For reasons which have been described in this paper the order of priority usually becomes: gain, beamtilt (which must be stable with frequency) lower side lobe suppression and null fill. The end position for null fill does represent some lack of appreciation of the significance of its value by some of the industry.

Fortunately the application of beamtilt has only a very small effect on gain; if a linear phase shift is applied to an antenna the gain a falls in proportion to the cosine of the tilt angle, so even for a 10-degree tilt the intrinsic reduction in gain is only 0.1dB. In the design of an antenna with adjustable beamtilt it is difficult to achieve a linear phase shift for all tilt angles and a slightly larger loss will be seen at extreme beamtilt positions.

Antenna designers face a significant challenge in achieving precise beam shaping over very wide frequency bands and a large range of (adjustable) tilt angles, but a wide range of design possibilities can be used to address this challenge.

Conclusion

A variety of techniques are available to antenna designers by which they can match antenna parameters to the needs of base station operators. As with many practical situations an improvement in one characteristic leads to undesired effects on other parameters. Practical solutions rely on an understanding of the priority of the functional parameters which must be provided to match the operational base station environment.

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