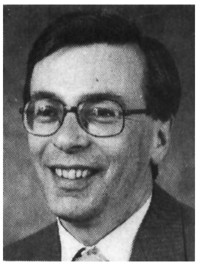
antennas for new mobile radio services



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Introduction

The past decade has seen unparalleled activity in mobile communications. Not only have new services been launched, but many existing systems have been extended or re-engineered to provide more facilities for users. The increased congestion of the spectrum is leading to the recognition of the unique role of radio as being above all the natural medium for mobile communications.

The ever-shrinking size of mobile equipment - now being reduced to pocket telephones which are no larger than small calculators - makes it almost impossible to provide a high-grain mobile antenna; system performance is entirely dependent on obtaining reliable base-station coverage. The spread of mobile radio from a small base of 'expert' users - who understood at least some of the basics of radio propagation - to the much less forgiving busy executive, and the increasingly competitive environment in which these services are now offered, increase the pressure to obtain complete and continuous coverage.

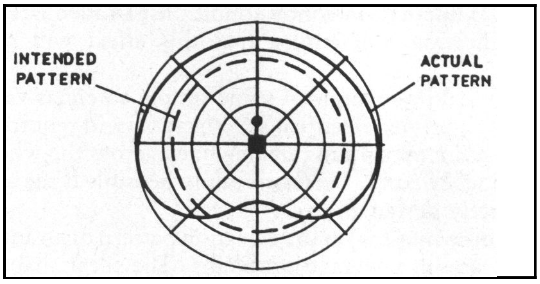
Base station antennas have become increasingly specialised as the need for high connectivity, high reliability and efficient spectrum use have been recognised. To understand how the specification of the antenna relates to system operation and reliability, the most important parameters are now looked at in detail.

Radiation Patterns

The radiation pattern of an antenna (sometimes called its polar diagram) describes the way in which an antenna distributes radio energy into the space around it. By specifying the right radiation pattern for a base station antenna we can ensure that energy will be radiated into the area in which the mobiles will be situated. This has a double benefit: not only will we increase the field strength inside the target area, but we will avoid energy being lost in other directions, allowing the re-use of the frequency in other areas by another service. Radio transmission and reception are reciprocal, so a further benefit is that the sensitivity of the base station antenna will be increased over the required service area and reduced in other directions, from which we can receive only unwanted mobiles who may be using the same frequency.

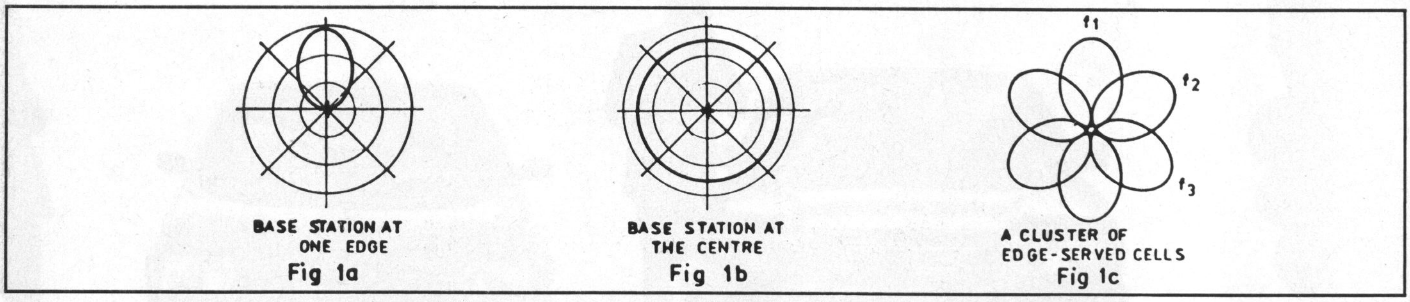
The Choice of Azimuth Pattern

When designing a mobile radio system we can choose to position the base stations either at the edge of the service area — in which case directional antennas will be needed (Figure la) — or within it. When they are located at the centre of the service area an omnidirectional base station antenna is needed, radiating signals equally in all azimuth direction (Figure lb)



Older practice was to select a prominent site - often on a hill top- and to use a simple omnidirectional antenna; often a dipole was used and was mounted on the side of the supporting tower, assuming that its pattern would remain roughly omnidirectional. Because of the shadowing caused by the mounting structure, the result was often large areas of sub-standard coverage combined with other areas in which the radiated signal was larger than intended, causing increased levels of interference (Figure 2). Modern systems increasingly employ properly designed arrays of elements grouped round a supporting tower, providing much more uniform and predictable service. The extra cost of this improved solution may be offset by the improved grade of service, or by installing a wideband antenna capable of providing this enhanced service to a number of separate users.

A further development which allows an increase in the density of mobile users is the formation of a cluster of separate service areas grouped like the petals of a flower. Each is served by a directional antenna mounted at a single multi-channel base station and operating on its own frequency (Figure l(c)).



BASE STATION AT ONE EDGE
Fig 1a

BASE STATION AT THE CENTRE
Fig 1b

A CLUSTER OF EDGE-SERVED CELLS
Fig 1c

Elevation Plane Patterns

The mobiles which are to be served by a typical base station are grouped in a small range of elevation angles, typically near- and somewhat below - the horizontal. Energy which is radiated above the horizontal is wasted; while the most distant communication, requiring the largest effective radiated power, takes place near the horizontal.

The weak link in most mobile systems is the link from the mobile to the base station. While both the mobile and base stations have receivers with comparable sensitivities, the mobile transmitter is often operated from small batteries and have an output power limited to a few milliwatts. Every measure which can increase the gain of the base station receiving antenna must therefore be examined very carefully.

Once the azimuth coverage of the base station has been determined, the only method which is available to increase the gain of the antenna is by reducing its beamwidth in the elevation plane. If this process is continued too far problems may arise. A narrow beam which is aimed exactly along the horizontal from a base station at a prominent location will pass over the heads of target users; by using electrical (or sometimes mechanical) beamtilt we can direct the beam maximum down to the direction of the outer edge of the required coverage area. An insecure mechanical support, or a flexible antenna, will allow the elevation beam direction to fluctuate in windy conditions; an adequate mechanical specification will ensure that this effect will not cause trouble.

The vertical beam angle of some simple antennas varies with frequency; a proper electrical specification will require that the elevation beam maximum remains fixed across the whole operating frequency band. This is certainly possible if the antenna is appropriately designed.

Nulls (deep minima) in the elevation pattern of an antenna can result in near-in coverage problems. The ideal shape for the elevation pattern of an antenna is one in which the electric field falls as cosec E E2 theta, where theta is the angle of depression below the horizontal. The specification of a null-fill function makes sure that the antenna will be designed to overcome these close-in problems, at least down to an angel of depression of 20 degrees or so, where the potential area which is affected will be very much smaller.

Gain

The interrelationship between the gain and radiation pattern of an antenna has already been mentioned. The complete picture is given by:

Gain = Directivity - Losses

It is clearly of little benefit to go on increasing the gain of an antenna by reducing its angular coverage if losses are allowed to increase at the same time. The increase complexity and distribution losses in a large antenna limit the gain which can usefully be achieved. An omnidirectional antenna is limited to around lOdBi, although directional antennas may have very much higher gains.

Siting

For the past three decades base stations have been placed on high terrain features; hills, tall buildings and the like. The result has been large coverage areas - but with the inevitable gaps caused by shadowing or multipath propagation. The penalty has been a very large area in which the signal is too weak to be reliably usable, but is large enough to prevent the re-use of the frequency by another user.

It is much more efficient to plan coverage using terrain contours to prevent- or at least reduce - the spread of signal beyond the area served. The base station is often sited at a lower elevation than the surrounding service area. Signal fall-off outside the coverage zone will now be much more rapid, permitting more intensive frequency re-use. A further improvement can be made by replacing single high power base stations by a number of low power installations. Such techniques have been seen as expensive in terms of the capital equipment and infrastructure needed, but when they can generate more revenue from an increased number of served users this argument needs to be re-examined. The new generation of cordless telephones (CT2) will show what can be provided when this approach is pushed much further than before, with closely-packed cells a few tens or hundreds of metres across, each using a base station of erp of only 10mW.

Urban Base Stations

There is now a very large body of data on street-level propagation in urban surroundings at frequencies up to and even beyond 1GHz. As the operating frequency rises the spatial variability of signals increases, there is a corresponding increase in holes in base station coverage which require a larger number of infill stations if continuous service is to be provided.

Coverage within buildings remains a mixture of careful study and good luck. Variables in building construction and internal layout cause large differences between superficially similar examples. Perhaps 'micro-cells' (one cell per structural room) or leaky feeders will prove more reliable techniques than firing in from outside or mounting downward facing antennas on the roof! Users often do not appreciate that a 900MHz radio system does not simply mimic a 27MHz pager; they will only accept the need for change when they not only see the additional facilities which they will be able to access, but understand how those facilities can save time and money, offsetting the large initial investment.

Availability

If we look at availability from the point of view of the user, it may be represented by:

Availability (%) = 100 - (% system outage)
- (% calls when channels are unavailable)
- (% of calls attempted in coverage holes)

In an emergency system all failures are critical and may cause loss of life or property; it is salutary to realise that a failure caused by system overload or patchy coverage is every bit as serious as if the system has become unserviceable. In a commercial environment, a service provider only sees the system outage, as to him it is measurable and represents a loss of revenue, the user will not know the reason, but perceives his inability to make (or less often, receive) his call.

This view of availability is not taken to demonstrate that outage time due to failure is unimportant, but to stress the need for a full analysis of all the causes of communications failure. In a commercial system the pattern of usage is relatively predictable and at least in theory it may be possible to provide extra channels to ease the pressure points. The user may be displeased by his inability to access a channel during a traffic jam in the system's busy hour, but his life is unlikely to be threatened. (A priority protocol for emergency calls could cope with this possibility.)

An emergency system must be engineered to operate within constraints which are much more difficult to quantify. The characteristics of day-to-day traffic on a network become reassuringly familiar, but a major emergency may bring together several hundred would-be users at a location which usually sees little radio traffic. Lightweight quick-erect masts and antennas are available to provide for the rapid deployment of high capacity base stations and links for use in this situation. These can be based on the use of small all-terrain vehicles, or may be suitable for independent deployment.

Reliability

An antenna failure will often totally disable a radio system; recovery action requires spare parts, skilled personnel and good enough weather to allow the work to be carried out. Unfortunately no adequate formal methods exist to predict the reliability of an antenna system with any real accuracy.

Throwing money at the problem does not guarantee a good and reliable system, but there is little doubt that in some sectors of the market the unwillingness of users to pay for good quality products has driven quality down to an unacceptable level, leading to poor reliability. Antenna designers are hampered by the severe difficulty of carrying out realistic accelerated life tests. At best, testing can compare a new design with an existing design whose practical record of field service-ability is known. The new one is 'better' or even 'much better'; but we can never quantify the change in terms of lifetime or MTBF, as the conditions of the test were, by definition, unrepresentative of the real world. Sudden arbitrary changes in procurement specifications should be avoided at all costs; they lead to the production of designs which have no evolved pedigree and carry unknown risks.

For many years radio and TV broadcaster have led the way in specifying systems which are fault tolerant. No single failure - even a major one - can lead to the loss of service, but only to the reduction of a parameter such as effective radiated power. The same security can be obtained by full duplication of failure and change-over to reserve equipment, but this method is expensive and requires increasingly complex monitoring arrangements (themselves prone to failure).

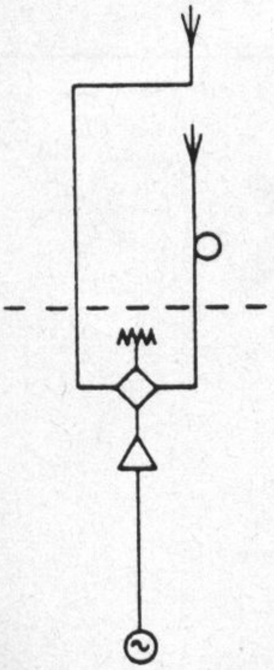


Fig 3a

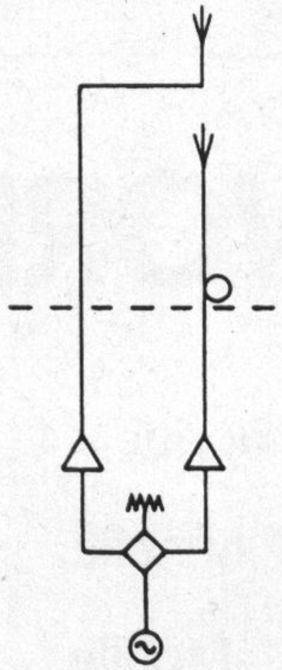


Fig 3b

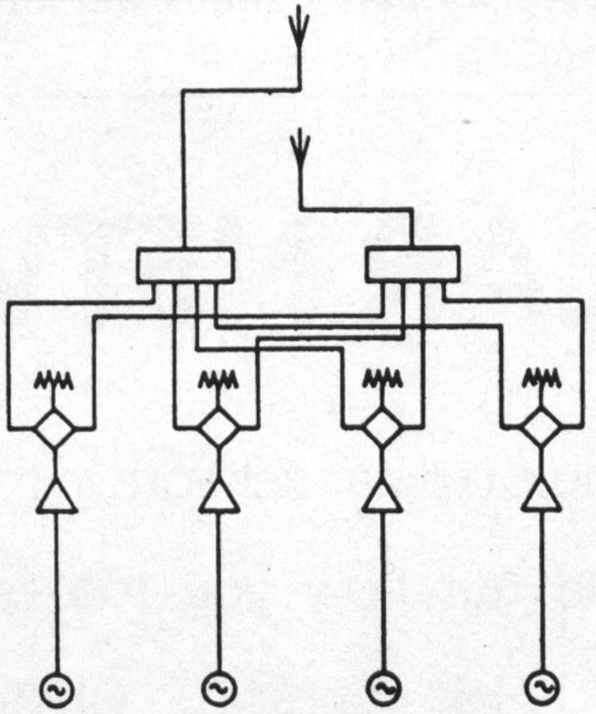


Fig 3c

One solution is the provision of parallel-operated systems in which passive networks provide for automatic fall-back to the reserve mode of operation. The system of Figure 3a is protected against antenna or cable failure; that of Figure 3b is also protected against the failure of an amplifier and may be provided with duplicated exciters to increase redundancy further. It is notable that duplicate redundant techniques are often used within quite small transmitters, but they seldom feed duplicate outputs to the antenna!

Multi-channel systems provide- some inherent redundancy, but the combining filters, feeders and antennas are often not duplicated and form a vulnerable point in the system. Figure 3c shows how these components may also be duplicated to provide much higher reliability. A further variation has been provided by antennas which incorporate matrices to permit frequency independent low-loss channel combining.

Failure

There are two main reasons for the failure of antennas, wind and rain. Both are in good supply in Western Europe. Unless antennas are well designed, wind-induced vibration causes parts to fracture by the mechanism of fatigue failure. Major failure by very strong wind is almost insignificant: no broadcaster or major radio system user lost antennas when a 160km/h storm swept across southern England in 1987. Instead failure occurs by continuous insidious vibration in only light or moderate winds. Aluminium - the most popular material for the construction of antennas - is particularly vulnerable to fatigue. A conservatively designed antenna will always stay in one piece longer than one in which smaller factors of safety are used, but it will cost more.

Water ingress is a significant electrical problem at frequencies above 500MHz, when even a single drop in a connector will cause a serious mismatch. The real problem, at all frequencies, is that of corrosion, for whenever water seeps in, corrosion will follow. Again, good design practices cost money and corner-cutting reduces life expectancy. Antennas with aluminium elements are capable of providing long and reliable service, but it is essential that joints between aluminium and other metals are designed to avoid electrolytic corrosion or rapid failure will be certain.

Daily temperature changes expose any slight imperfections of sealing. Daytime sunshine raises the temperature of exposed equipment at 60°C or more, even at a latitude of 55N. Temperatures fall rapidly at sunset or at the onset of rain showers. Voids which are supposed to be sealed should be regarded with great suspicion; it is much better to specify that voids must be filled or freely vented and provided with a drain hole to allow condensation to escape.

Cables and connectors are often found to be penetrated by moisture. Unfortunately many of the usual flexible covers trap water rather than excluding it, and many years' experience has shown that there is little to better the use of grease-impregnated wrapping tapes.

Good standards of installation practice are very important; their achievement relies on the use of good quality labour to carry out the work. Antennas need to be supported rigidly or any tendency to vibration may be made worse. The proper routing and securing of cables - away from damage by climbers' boots and falling ice - is also important if the system is to provide reliable service. Foam-filled cables are now in general use and enjoy an excellent record for reliability if they are properly installed. When the cable is large and inflexible a separate, flexible connecting tail is desirable to avoid straining the antenna input connector especially when a panning operation is needed to determine the proper orientation of the antenna.

In Conclusion

The recent upsurge in the popularity of mobile radio systems, and the large revenues which they now generate have led to a demand for better engineered systems with higher reliability. Pressure on spectrum availability has led to the adoption of cellular and micro-cellular system architectures.

The proper siting of base station antennas must be considered as a central part of system design. The most satisfactory service to users will only be obtained when antennas are specified and selected with the same care as the other performance-critical components of the system.

Biography

Brian Collins joined C&S Antennas after graduating from University College London more than 25 years ago and is now their Technical Director. He has worked on a wide variety of antenna projects for both military and civilian applications covering most of the commercially exploited radio spectrum. Brian is a member of the Institution of Electrical Engineers and is a regular contributor to conferences and technical committees.