

Embedding Antennas in User Equipments

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Abstract— This review paper describes some of the practical problems frequently encountered when antennas are integrated with user devices such as handsets, laptop computers, wireless access points and earphones and suggests a range of solutions that have been shown to increase antenna efficiency.

Index Terms—Antennas, Wireless LAN.

I. INTRODUCTION

THE increasing miniaturisation of a wide variety of electronic equipment has led to a general requirement to integrate one or more antennas into the same package as the RF transceiver and digital electronics. While a wide variety of information is available about the design of suitable antennas, very little published information examines the intrinsic interaction between the antenna and the device on which it is mounted. This interaction becomes more significant as the dimensions of the device become smaller in terms of the operating wavelength; as the longest dimension falls below about one wavelength the interactions dominate the achievement of adequate antenna impedance matching and radiation efficiency. Interactions with the user or with other hardware, perhaps mounted on the same motherboard, often contribute to further loss of desired performance. Small antennas are subject to internal losses, but their gain/efficiency is usually dominated by reflection loss caused by imperfect matching, especially at the edges of the operating frequency band.

This paper provides a review of the relevant phenomena and describes general solutions that can be implemented during the early design stages of equipment with embedded antennas; these apply to almost any type of antenna, whether an integrated LTCC chip, a dielectric-loaded patch or a simple radiator printed on the module PCB.

II. BALANCED AND UNBALANCED ANTENNAS

In view of the general pressure on available dimensions it has become normal practice to employ unbalanced antennas for almost all embedded antenna applications. An unbalanced antenna (such as a whip or monopole) is one with a single terminal fed against ground, generally by means of a microstrip or coaxial transmission line. This configuration intrinsically uses the groundplane as part of the antenna. When the groundplane is large the RF currents associated with the antenna

cover only a small proportion of the available area, but as its dimensions are reduced the whole groundplane supports currents that are essential to the radiation process.

A balanced antenna (such as a dipole) has two terminals and is fed by applying a voltage across them, independently of local ground. Although some currents are excited in the nearby groundplane, the radiation process is not essentially dependent on their existence and the radiation properties of the antenna are less affected by the groundplane dimensions. Fig. 1 illustrates these basic forms of antenna.

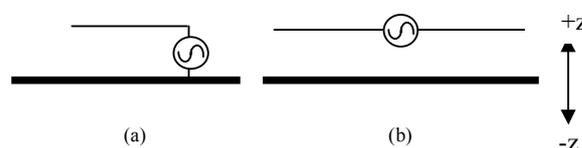


Fig. 1: The essential difference between an unbalanced antenna (a) and a balanced antenna (b).

It is obvious that even with the balanced antenna the presence of the groundplane will modify the behaviour of the antenna, but the extent of the groundplane, especially in the $-z$ direction, will have far less effect in the case of the balanced antenna. Methods by which an antenna conductor may be shortened – by loading, meandering or any other technique – can be applied to both balanced and unbalanced antennas but unbalanced antennas are usually favoured because they are intrinsically smaller and have lower cost than balanced antennas. The penalty of this choice is greater intrinsic dependence on the properties of the groundplane.

The advantages of balanced antennas can be used at higher frequencies where antenna dimensions are intrinsically smaller and their performance advantages merit their use [1, 2].

III. GROUNDPLANE EFFECTS

When an unbalanced antenna is mounted on a short groundplane, it is currents in the groundplane that give rise to much of the radiation [3–5]. Fig. 2 shows the field on a plane close to a standard planar inverted-F antenna (PIFA) mounted at the end of a groundplane about $\lambda/4$ long. The fields shown are those on a simulation plane parallel with the groundplane and about 50mm above it. Fig. 3 shows the relative bandwidth that can be obtained from an antenna mounted on groundplanes of various lengths. The optimum bandwidth is obtained with a groundplane with a long dimension of about 120mm in the 900MHz GSM band and 44mm in the 2.4GHz ISM band. To

Manuscript originally received on October 3, 2006 and in revised form on January 6, 2007..

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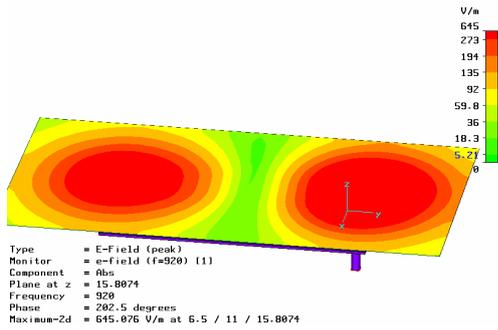


Fig. 2: E-field illustrated on a plane parallel with a PCB module about a half-wavelength long. The antenna is mounted on top of the right-hand end of the PCB. It is clearly seen that the entire PCB is involved in the radiation process.

achieve this bandwidth the antenna must be mounted at one end of the board; much smaller bandwidth will be obtained if it is mounted at a position along the long side of the board – the bandwidth depending on its exact location. While bandwidth may not be a great concern in the 2.4GHz ISM band, the result of changing the size of the groundplane or the antenna position may radically change the antenna input impedance.

Antennas are usually mounted off the edge of the groundplane, so there will be strong local electric fields between the antenna and the groundplane, and large currents flowing along its edges. RF currents will be induced in any circuit tracks or components that lie in this region, so to avoid the loss of RF energy precautions are needed to ensure that the tracks and other components are screened as well as possible and that any unavoidable RF currents encounter as little resistance as possible. The need to provide the largest practicable groundplane size means that the most desirable solution is to provide continuous groundplanes on both outer faces of a multi-layer board, with a series of vias connecting these at the edges of the device. When this solution is not practicable, the groundplane on one face of the PCB should be continuous; the other face should be covered with copper in regions where strong RF currents are likely to flow and the two groundplanes joined with vias at frequent intervals.

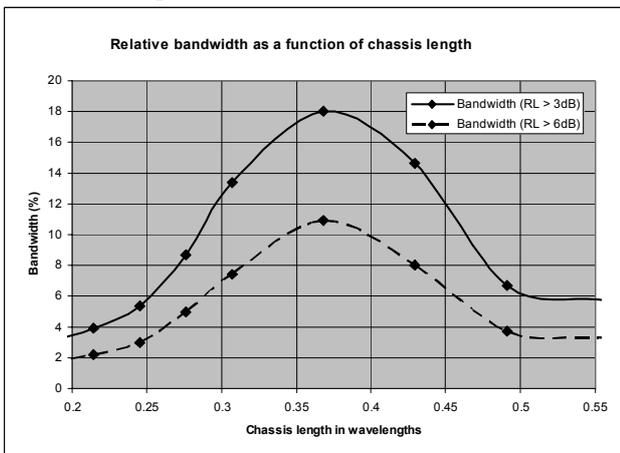


Fig. 3. Relative bandwidth available from an antenna as a function the electrical length of the groundplane on which it is mounted.

Designs in which different areas of the faces of the PCB have

separated groundplanes should be avoided because RF fields will exist between their edges; although these will contribute to radiation they will increase dielectric losses. All external groundplanes on both board faces should be contiguous and connected together with vias.

IV. ON-GROUNDPLANE AND OFF-GROUNDPLANE ANTENNAS

There are two major classes of small unbalanced antennas, those which extend from the edge of the groundplane and those which are mounted above the groundplane (Fig. 4). The on-ground plane antennas generally have smaller bandwidths, but their use allows the reverse side of the board to carry components below the antenna – with high component packing densities this arrangement is often attractive. A further difference is that with an off-groundplane antenna the local (stored energy) fields around the antenna extend on both faces of the PCB; with an on-groundplane antenna the local fields are concentrated on the same face as the antenna, so there is less local interaction if the module carrying the antenna is mounted parallel with a motherboard, as in Fig. 5.

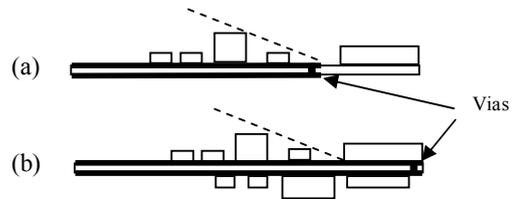


Fig. 4. Off-groundplane antenna (a) and on-groundplane antenna (b). In both cases the groundplanes on both sides of the supporting PCB are bonded at their edges with vias. The dashed line, inclined at about 30°, indicates the typical clearance needed for components mounted close to the antenna.

The region close to the antenna is exposed to relatively intense local stored-energy fields which induce RF currents in conductors to which they couple. The oblique lines in Fig. 4 provide a rule-of-thumb guide to the keep-out zone that should generally be observed for standard chip components or screened packages. Components that do not have an outer grounded shield are to be avoided close to this zone, as RF energy will be coupled into other functional circuits where it will be absorbed. Components attached with wires are particular offenders, as even when mounted some distance from the antenna they will couple energy from the RF currents flowing on the groundplane. Batteries often have DC-positive cases, so effective RF decoupling must be provided to prevent RF currents being lost into the +DC supply line.

V. ANTENNAS ON SMALL MODULES ATTACHED TO MOTHERBOARDS

When designing a small module to be mounted on a larger motherboard it is important to appreciate the strong dependence of antenna characteristics on groundplane size. Such applications include standard Bluetooth® modules designed to be mounted into printers and other user equipment, and to RF devices integrated in USB dongles. The ground connection

between the module and the motherboard forms an important RF connection; its inductance, geometry and the extent of coupling between its conductors critically affect the RF performance of the module. Leakage of RF currents into DC feed circuits and data lines results in poor RF performance which must be addressed by changing the interconnection arrangement. The general principle of good design is to provide a short, stable, low-impedance ground path between the module and the motherboard and to insert RF chokes into DC and data lines close to the connection. On some occasions it may be better to completely isolate the module with RF chokes in all the lines and the ground connection. If the data connection is unavoidably made with a long cable, a separate short RF ground connection should be provided. (See Fig. 5.)

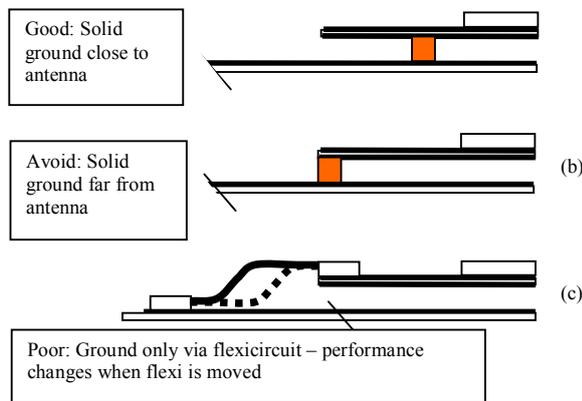


Fig. 5: Grounding arrangements for modules on motherboards

There is currently a wide variation in the design of the RF circuits in WLAN, Bluetooth® and other RF chips. The complexity and attenuation of the circuits which must be provided between the RF chip and the antenna vary correspondingly. These require careful layout and design; transmission lines (usually coplanar waveguide with underlying groundplane) must be dimensioned to have the correct characteristic impedance and all the RF circuits must have a groundplane below them, bonded to the main RF groundplane with regular vias. A discontinuous ground path inevitably gives rise to mismatch and excess attenuation. It is to be expected that an L-C matching network will be needed between the antenna and the feed circuit because however well-matched an antenna when mounted on an evaluation board, for the reasons explained above its impedance will change when it is mounted on the real PCB.

VI. GAIN AND RADIATION PATTERNS

The power available from typical RF chips is low and the demand for operational range by users is high, so there is strong pressure on designers to achieve the highest possible radiated power (within regulatory limits) from their devices. There is also pressure to reduce the power requirements of devices, so simply increasing the output power is often no real solution. Success relies on antenna placement, appropriate coupling circuits and the performance of antenna itself.

A single small antenna allows the designer only limited control of its radiation pattern, which is generally determined by antenna location relative to the groundplane and the placement of the RF module relative to other conducting components forming the communicating device. The designer will often have little knowledge of the relative placement of the device relative to the other end of the radio link(s), so unless the user can control these the best option is to aim for quasi-omnidirectional coverage. The relative polarization of the device as seen from the base station is likely to depend on its physical orientation, so for most purposes it must be regarded as essentially random. The radiation patterns shown in Fig. 6 were measured using an off-groundplane monopole antenna mounted near one corner of a module on a groundplane 90mm x 52mm. The patterns show field strengths in polarization planes parallel with and orthogonal to the groundplane. Fig. 7 shows results for a PIFA on a smaller module.

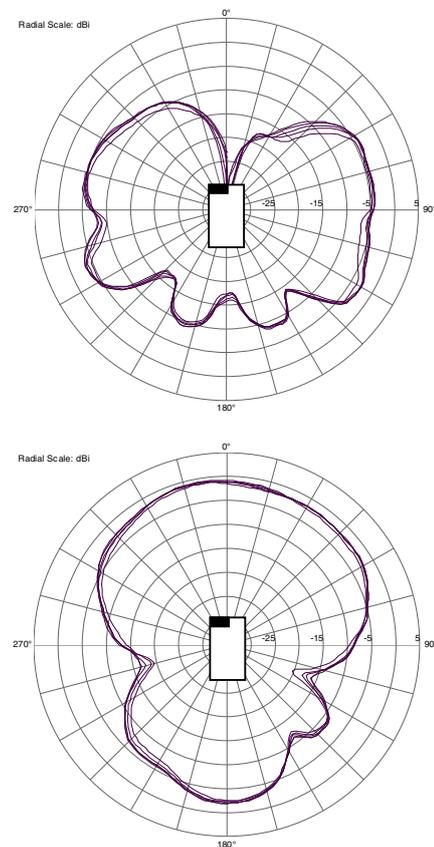


Fig. 6, Radiation patterns of an off-groundplane monopole antenna on a small module. The dimensions of the module and antenna position are the very significant factors in determining the shape of these patterns. Curves relate to frequencies in the range 2.4 – 2.485GHz. The upper plot is for the polarization component in the plane of the paper and the lower plot is for the orthogonal polarization.

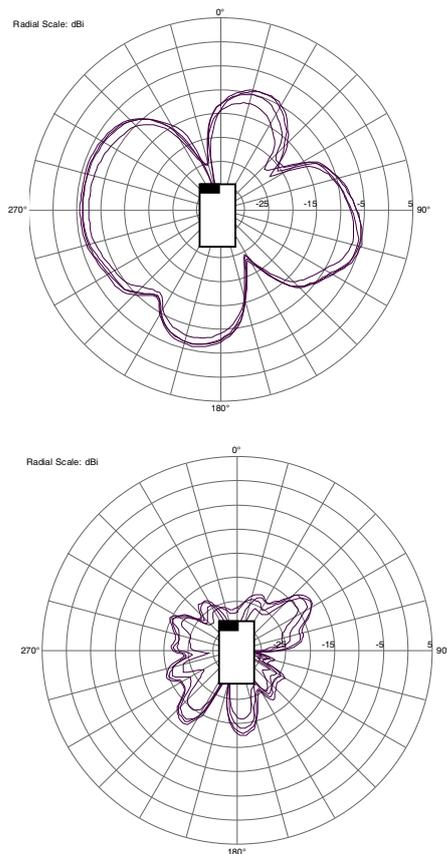


Fig. 7. In this example the antenna is an on-groundplane PIFA mounted on a very small module (22 x 40mm). Here the radiation is much more strongly polarized in the plane of the device groundplane. It can be seen that the copolar pattern (top) is approximately aligned with the diagonal of the groundplane.

Propagation between mobile devices and access points, especially in indoor environments, occurs by multiple paths and the interaction of signals arriving by different paths gives rise to frequency-dependent spatial fading whose effects can be mitigated by using diversity techniques at one (or both) ends of the link [6]. The placement of antennas to achieve effective diversity presents a new challenge on electrically small devices. Spatial diversity requires two antennas physically separated by a substantial fraction of a wavelength. On a small device the separation of the antennas is limited by the device dimensions and in many cases separate antennas couple into the same groundplane current modes, creating higher correlation than might otherwise be expected. Polarization diversity, which is well established for use in mobile phone systems, can be achieved with two separate antennas or a single (but larger) antenna and its use can reduce the coupling caused by common groundplane modes.

The existence of multiple independent propagation paths can also be exploited by the use of MIMO techniques in which separate antennas transmit different coded information, making use of the environment to provide enhanced spectral efficiency. This requires antennas with sufficient isolation and lack of correlation in the receive path to enable the individual

signals to be recovered by signal processing [7].

Fortunately the effect of mounting small low-directivity antennas at different locations on a user device is to create multiple quasi-omni radiation patterns with their maxima and minima differently oriented in space, so a significant amount of ‘pattern diversity’ is also available – the weighting of signals traveling by different paths is different for each antenna, and this property can be exploited both by simple diversity methods and by MIMO processing.

VII. CONCLUSION

The RF performance of modules with embedded antennas is a complex function of the interaction between the antenna, the groundplane of the module, the components mounted on the module and the environment in which it operates.

ACKNOWLEDGMENT

The simulation in Fig. 2 was created using CST *Microwave Studio* and the radiation patterns in Figs 6 and 7 are used by permission of Antenova Ltd.

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