Antenna and Radio Integration for Mobile Platforms

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INTRODUCTION

The performance of antennas on a small mobile platform is heavily dominated by the effect of radiating currents excited in the platform’s chassis – the PCB and other conducting hardware connected to it. As well as providing radiation from the handset these fields create limits on the designer’s ability to control SAR, hand and head effects and hearing aid interference. This paper shows how the adoption of balanced antennas can create new possibilities for antenna performance and can also create new possibilities for the integration of RF circuits into antenna structures.

COUPLING BETWEEN ANTENNAS AND THE CHASSIS

Fig.1 shows the fields existing a short distance from the chassis of a typical device in both the low and high bands (850/900 and 1800/1900MHz). In both band groups these fields are typical of a dipole of the same length as the chassis; the far-field radiation patterns and polarization of the device correspond with these fields.

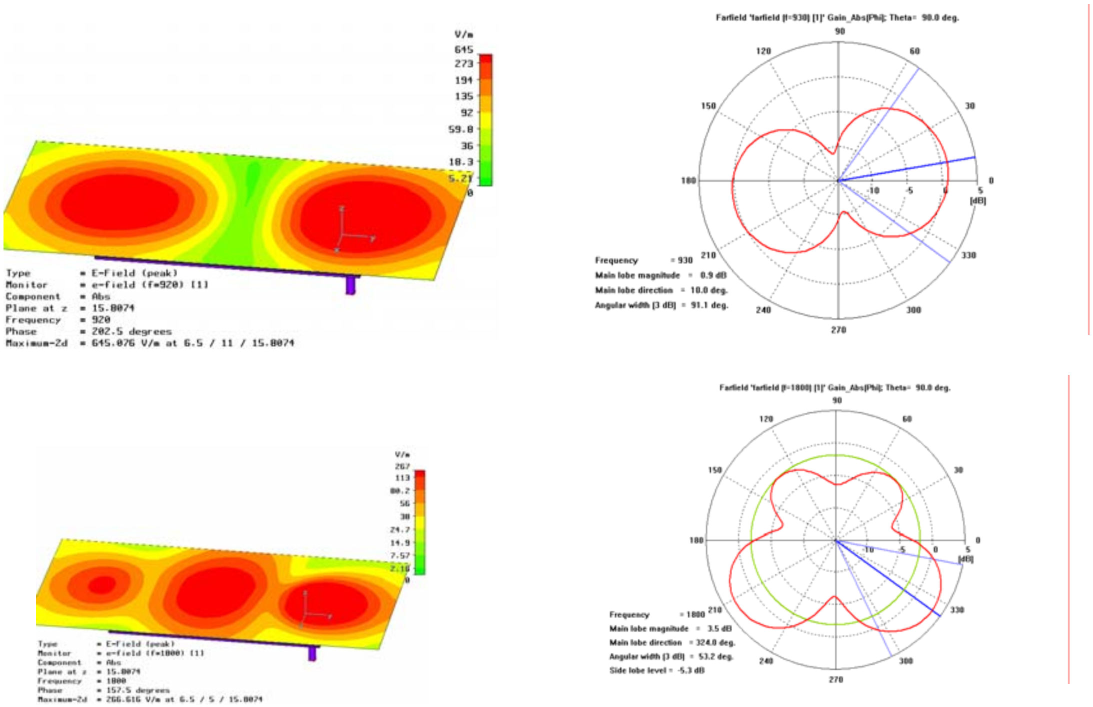


Fig 1: Local fields in a plane close to the chassis of a small mobile device and corresponding equatorial radiation patterns at low bands (Upper) and high bands (lower).
Simulations created using CST Microwave Studio.

This effect has positive benefits in the low bands, as an antenna with a volume of 3 – 5ml is unable to provide the required operating bandwidth. Unfortunately the corresponding negative consequences of extensive chassis currents cannot be ignored. The SAR exposure of the user is not easily controlled – after ensuring that the user is shielded from local fields associated with the antenna itself, we can go little further in reducing user exposure. The absorption of RF power by the user’s head and hand are difficult to reduce – they are simply a natural consequence of effectively grasping the radiating surface (the chassis), which is isolated from the user by only a few millimeters of plastic case, and placing it within a few centimeters of the head. As high chassis fields are an inevitable accompaniment of obtaining both high efficiency and wide bandwidth from a small device, the level of interference to a susceptible hearing aid is affected less than we may expect by details of the antenna design. Although some design approaches may make things worse by exposing the user to near field (stored) energy, there is a clear relationship between the fields necessary to radiate the intended power from the mobile device and the magnitude of the local fields around it. Any attempt to reduce the radiated power will be countered by the power control algorithms of the air interface: the base station will simply command the mobile to radiate more power.

The necessity of exciting ground plane currents in the low bands to achieve sufficient bandwidth has led to the widespread use of unbalanced antennas in mobile equipment. The antenna return current is deliberately caused to flow in the ground plane and the desired radiating chassis modes are excited. The same antenna structures are commonly also used in the upper frequency bands. While this tactic works well in the high bands as far as impedance and radiation pattern bandwidth are concerned, it continues to create the subsidiary negative effects discussed above. In the high bands the antenna structure itself has a volume 8 – 10 times larger (in cubic wavelengths) than in the low bands, so the intrinsic bandwidth of the antenna is now larger and it becomes worth challenging the common practice of using an unbalanced antenna in both bands. A balanced antenna would radiate directly from the antenna elements and would generate little in the way of chassis currents, potentially allowing the realization of higher in-hand efficiency, lower SAR and lower hearing aid interference.

The existence of common-mode chassis currents created by each separate unbalanced antennas on a shared platform limits the isolation that can be obtained between antennas for different services. The use of balanced antennas offers a method by which this troublesome coupling can be considerably reduced.

BALANCED ANTENNAS

While an unbalanced antenna has only a single terminal and is driven against the local groundplane (Fig.1a), a balanced antenna is one with two terminals exhibiting equal impedances with respect to the local groundplane. These two terminals are excited with respect to ground by equal voltages with a phase difference of 180°. This slightly unusual definition makes it clear that there are two ways in which we can imagine a balanced structure (Fig.1 b,c). Fig.1c provides a useful insight into an alternative way of realizing a balanced structure by using a complementary pair of unbalanced structures. Each of the unbalanced antennas can use the compressed formats, for example PIFAs, which have become usual in small wireless devices [1, 2].

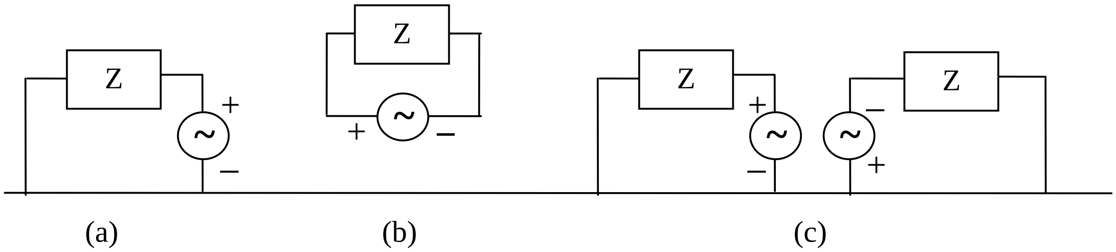
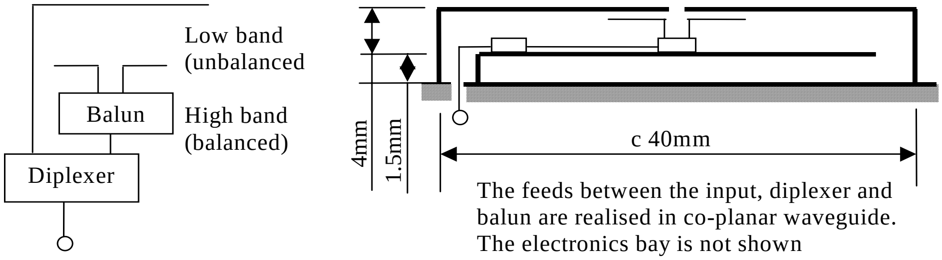


Fig.1: (a) Unbalanced antenna, (b, c) balanced antennas

The dimensions of a balanced antenna are almost inevitably larger than those of an unbalanced antenna (for the same impedance bandwidth) so although a balanced structure is entirely practicable for the upper bands (1500 MHz and above), in the lower bands (800-900 MHz) they are generally too large and occupy too much PCB area to be acceptable in a modern handset. Also, the Chu-Harrington limit for electrically small antennas [3, 4] dictates that the antenna alone is too small to radiate effectively in the low band and so, as we have already seen, the antenna operates only because the groundplane (chassis) supports significant radiating currents. The challenge, therefore, is to devise a structure that can function in a balanced mode in the higher frequency bands and in unbalanced modes in the lower bands. Fig.2 shows a practical way of realising this whilst maintaining a conventional 50 ohm unbalanced feed into the antenna.



The feeds between the input, diplexer and balun are realised in co-planar waveguide. The electronics bay is not shown

(a) Schematic **(b) Physical arrangement (not to scale)**

Fig.2: Physical arrangement of the hybrid balanced/unbalanced antenna

CONFIGURATION

The circuit required to drive the balanced/unbalanced pair from a conventional unbalanced 50-ohm input is shown in Fig.2a. A chip diplexer is used to divide the high- and low-band signals. The high-band signal is fed to a balanced antenna via a chip balun and the low-band directly drives an unbalanced antenna. The radiating elements are physically arranged in a stack as shown in Fig.2b. It will be seen that the balanced high-band antenna is driven from the balun by capacitively coupled plates; this arrangement avoids short-circuiting the low-band feed. The low-band connection from the diplexer is connected to the low-band radiator on which it is placed, but this connection has been omitted from Fig.2b for the sake of clarity.

The whole arrangement is very compact and is implemented in a single flex-PCB (Fig.3). This design is the subject of two UK patent applications [5, 6]. The groundplane shown in Fig.2b is the upper surface of the optional electronics bay where the RF circuits and devices can be located. The low-band radiator is only 1.5mm above this ground, while the high-band radiator is 4mm higher. The total height of 5.5mm is close to the lower limit for normal multi-band antennas. With a 1.5-mm high electronics bay underneath the antenna, the overall height is 7mm and most or all of the RF components can then be contained inside the antenna.

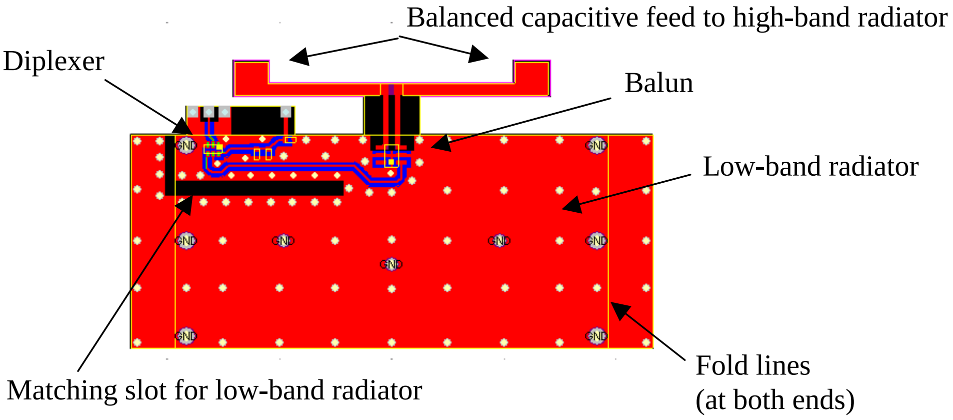


Fig.3: The low-band radiator (flexi-pcb)

MEASURED RESULTS

The Return Loss shown in Fig. 4 is greater than 6dB across the GSM900/1800/1900 bands. A 0.5pF shunt capacitor between the two antenna arms was required to match the high band component, but no low band matching was necessary. Figure 5 shows the free space efficiency to be 40% or better across all three bands. It is clear that the high band has a lower average efficiency than the low band. In part this is due to the added insertion loss through the balun.

Whilst the efficiency measurements are reasonable, there are two factors that must be taken into account when comparing them with other antennas.

Firstly the antenna is remarkably stable under various loading conditions, such as when hand- and head-loaded in the talk position. A VSWR less than 4:1 in the high band and 7:1 in the low band was recorded under all load conditions that were tested; this included the phone resting on a metal surface. An antenna that presents a stable VSWR to the power amplifiers is a considerable advantage when designing the RF front-end of a mobile phone.

Secondly the efficiency measurements of Fig.5 were made through the diplexer and balun which generate an insertion loss of 0.7dB in the low band and 1.4dB in the high band. These components were introduced so that the antenna could be driven from a conventional unbalanced 50-ohm feed. For example, a quadband GSM front-end module (FEM) would normally use 6-way, 1-pole switch with an unbalanced output to the antenna. However if the low band unbalanced antenna were driven through a 3-way 1-pole switch and the balanced high band antenna were driven through a balanced 3-way 2-pole switch then the need for a diplexer and balun could be avoided and the antenna efficiency would be correspondingly higher. This arrangement would be most beneficial if the high band power amplifier (PA) had a balanced output.

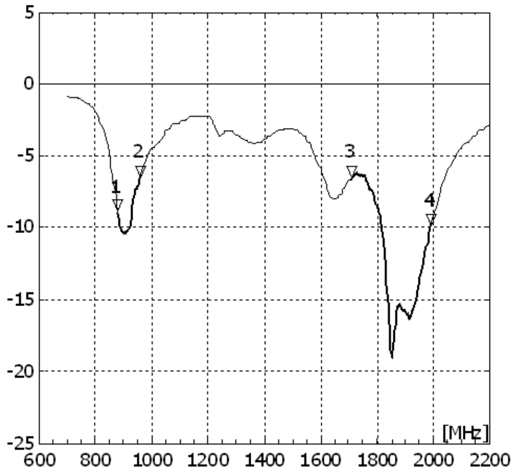


Fig. 4. Return Loss of tri-Band antenna module, measured through the diplexer and balun.

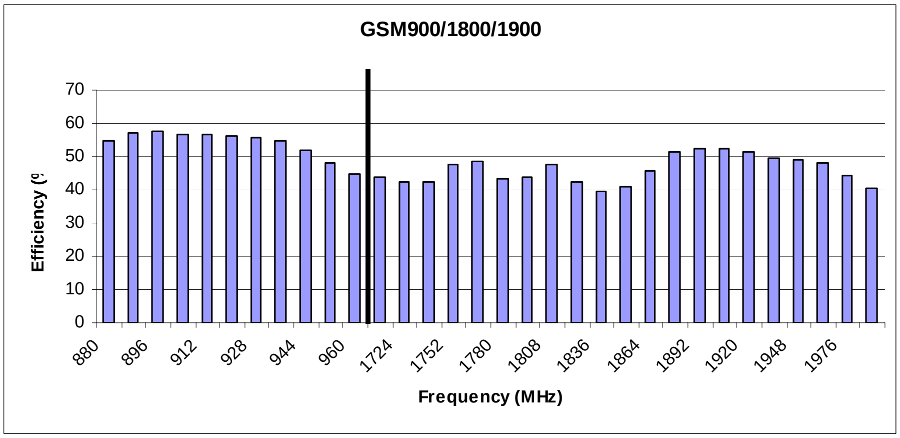


Fig. 5. Efficiency of tri-Band antenna module, measured through the diplexer (low band) and the diplexer and balun (high band).

Once the front-end modules and PAs are designed specifically to work with the antenna, and are enclosed inside the antenna, then the structure can be considered as a single radio-antenna module and may be further optimized. For example, it is no longer necessary to stick to a conventional 50-ohm impedance and other PA output impedance/antenna input impedance combinations can be considered in order to jointly optimize the performance of both antennas.

CONCLUSIONS

With the development of the radio-antenna module, the antenna should no longer be considered as a stand-alone component. It should be designed to work with other RF components and be integrated with them. This not only saves space and improves efficiency but also enables some long held views on antenna design to be challenged. In the high bands, balanced configurations can be used that offer considerable immunity to hand, head and other forms of environmental loading and are likely to become the standard design approach in the future. In the low bands, however, a significant percentage of the radiation is due to groundplane (chassis) currents and careful mechanical and electrical design of the chassis is required to achieve efficient antenna performance.

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