IMPROVING THE RF PERFORMANCE OF CLAMSHELL HANDSETS

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SUMMARY

This paper examines the interaction between the antenna performance and the geometry of mobile radio handsets. After a survey of previous work on bar phones, the paper examines the issues which affect the design and placement of antennas on clamshell phones and discusses practicable design strategies to optimise their efficiency.

INTRODUCTION

The designers of handsets for mobile radio networks are subject to pressures to integrate more and more functionality into handsets whose dimensions, led by the expectations of the market, shrink with each new generation of designs. This pressure is accentuated by the demand for power created by large colour displays and cameras, while the dimensions available for batteries are stringently limited. On examining the link budget for a mobile radio system it is very obvious that the low gain of a typical handset antenna is an area capable of significant improvement. For the network operator the modest RF performance of handsets limits their coverage, while for the user it not only degrades the service they enjoy, but also significantly diminishes battery life (talk time). This article discusses the important interactions between aspects of the design of the handset and the RF performance which can be obtained from it. As will be seen, acceptable RF performance is not just a matter for the antenna designer, but depends on an understanding of the underlying issues on the part of the whole handset design team.

THE EFFICIENCY OF A HANDSET

An ideal handset antenna would radiate all the power delivered to it by the power amplifier. The terminal efficiency of the antenna is the ratio of the total power radiated to the forward power delivered to it. In practice the efficiency of a handset antenna is much less than 100%, especially in channels located close to the edges of the operating frequency band. Even when a handset is measured in a test fixture, with no user's hand or head present, it is common for the efficiency to fall below 50% at the band edges, and examples with much lower band-edge efficiencies – sometimes even below 20% – are present on the market. The efficiency of a handset will fall further when user holds the handset and place it against their head. There are three significant contributors to this loss of efficiency:

- The imperfect impedance match of the antenna at the band edges gives rise to a very significant reflection loss;
- RF currents may be coupled into other components of the handset, allowing it to be dissipated inside the phone;
- Ohmic and dielectric losses convert useful RF energy into heat in the antenna and any associated matching circuits.

The order of importance of these factors will depend on the design of the handset, but in the lower frequency band (850 or 900MHz) reflection loss is likely to dominate once reasonable precautions have been taken to minimise the other factors.

BAR PHONES

Simple bar phones have been extensively studied and it was reported some time ago [1, 2] that the impedance bandwidth of the antenna on a bar phone is a function of dimensions – particularly the length – of the chassis of the phone. A typical measured relationship between bandwidth chassis length is shown in Fig. 1 (and see also[1]). Although the design of the antenna influences the bandwidth obtained, different workers report the same characteristic curve shape. The length at optimum bandwidth depends on the width of the chassis; as expected the resonant length decreases as the chassis becomes wider.

The radiation pattern of a bar phone at the lower operating band (Fig. 2) is similar to that of a half-wave dipole parallel with the long axis of the phone; radiation is polarised along the phone axis. The chassis behaves as a half-wave radiator, excited by the antenna. The 'antenna' accounts for very little radiation, and its real function is to couple energy from the feed to the chassis. This is not surprising, as the antenna has a typical volume of only 6 x 40 x 15mm (= 3.6ml, or 0.00011 cubic wavelengths), and sufficient bandwidth cannot be obtained from such an electrically small device [3, 4]. Fig.3 shows a simulation of the electric field over the handset made using CST Microwave Studio™; the region of intense field is confined to the antenna. In Fig.4 the E-field is plotted on a plane alongside the handset; this clearly shows the dipole mode excited on the chassis and explains the pattern, polarisation and bandwidth observed. The simulation plane has been displaced from the centre of the handset to avoid cutting through the antenna, as the intense stored fields in the antenna dominate the result and the radiating mode is not seen.

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TWO-PART CLAMSHELL PHONES

In recent years clamshell handset designs have taken an increasing part of the handset market. A typical clamshell handset is around 85mm long when folded and 140 – 160mm long when opened. Reference to Fig.1 shows that from an electrical point of view this is an unfortunate choice of dimensions, as the handset is too long for optimum performance when open and too short when closed. Worse, the current maximum in the centre of the handset falls in the region of the flexi-PCB (F-PCB) connecting the upper and lower components of the handset. Not only will this high RF current give rise to dissipation in the F-PCB, but it will give rise to unwanted coupling between RF currents and the digital signals in the F-PCB. The current maximum is easily seen in Fig.5, in which the absolute magnitude of the current in the F-PCB is comparable with that in the antenna itself.

If we consider the RF circuit presented by the handset to the radiating dipole current mode, it will appear as shown in Fig.6, with the upper and lower components coupled by the inductance presented by the F-PCB and the capacitance existing between the two chassis – often determined by mechanical details of the design of the hinge. These two vital RF parameters are often determined by stylists and industrial designers, and not by RF engineers. It is easily seen that if the L-C combination is parallel resonant, a very high impedance will be created between the handset components and the resulting bandwidth will be similar to that of a handset having only the length of the 'driven' chassis – the one with the antenna on it. Variation of the L-C values either side of resonance will create a net L or C between the components. Repeated simulations and practical measurements have shown that – as may be expected – a net inductance reduces the achievable bandwidth because the total chassis appears electrically even longer than its physical dimension. As the net reactance becomes inductive the bandwidth typically increases rapidly up to some optimum net C, and thereafter decreases more slowly. Effects of this kind were first reported by Hirose and

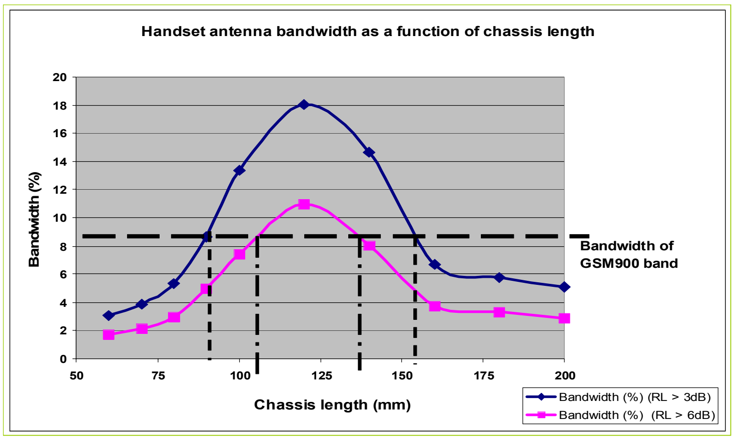


Fig 1: Bandwidth of a sample handset antenna a function of chassis length. The two curves show the bandwidths at -3dB and -6dB return loss. The example does not include external matching.

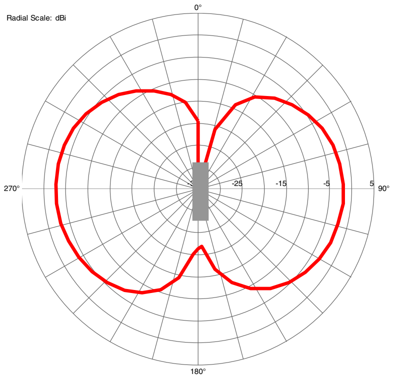


Fig.2: Measured radiation pattern of a barphone at 850MHz

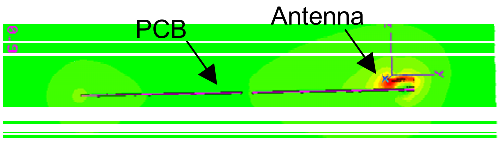
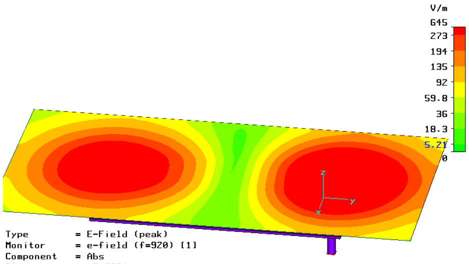


Fig. 3: E-field on a plane through the centre-line of the handset



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Type          = E-Field (peak)
Monitor       = e-field (f=920) [1]
Component     = Abs
Plane at z    = 15.8074
Frequency     = 920
Phase         = 202.5 degrees
Maximum-2d    = 645.076 V/m at 6.5 / 11 / 15.8074
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Fig. 4 E-field on a plane displaced so it does not cut though the phone (scale is re-normalised)

Miyake [5, 6, 7] but clamshell handsets were not usual at that time and their early work was not noted by later authors, for example Sugiyama et al [8]. If the series inductance is large it may be difficult to achieve a small enough capacitance to provide the optimum impedance. Conversely if the series inductance is too small it may be difficult to engineer enough capacitance to bring it to resonance (and the rate of change of reactance with frequency near resonance will be large, leading to further potential bandwidth limitation). The optimum net reactance sometimes has a very critical value.

Optimisation requires very careful management of the *electrical* design of the hinge and the adjacent ends of the two components of the phone, and requires close co-operation between the antenna designer and the mechanical and industrial designers responsible for the handset.

ANTENNA POSITION

Antenna position needs careful consideration. The two end positions for the antenna are fairly symmetrical, except that there is little thickness available in a typical flip, which generally forms the upper part of the phone. An alternative common position is close to the hinge, generally in the lower (main) component of the phone. This position has a number of major drawbacks:

- The antenna is driving the current in the chassis from the position of current maximum, but this is intrinsically difficult: a typical PIFA excites E-field (which is fine when the antenna is at the end of the chassis) and has not much ability to excite current in the chassis.

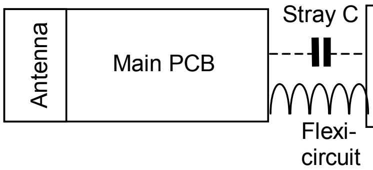


Fig. 6: Equivalent circuit showing the effect of the flexi-circuit and the inter component capacitance

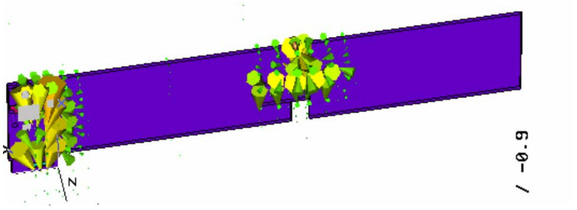
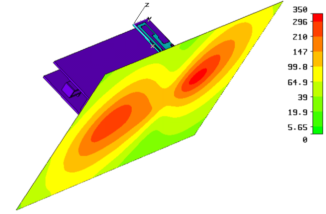


Figure 5: Simulated surface current density on a clamshell chassis. The current density in the region of the connecting flexi-circuit (center) is comparable with that on the antenna (at left).

Fig. 7: The input impedances shown on these two Smith charts were obtained by adjusting only the inter-component reactance; the antennas were entirely unchanged



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Type         = E-Field (peak)
Monitor      = e-field (f=944) [1]
Component    = Abs
Plane at x   = 41.8075
Frequency    = 944
Phase        = 45 degrees
Maximum-2d   = 349.694 V/m at 41.8075 / 8 / 0.05
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Fig. 8 (left): Clamshell phone in the folded position The characteristic dipole mode excitation of the groundplane is still obvious in this E-field plot. The antenna and flexi-circuit can be seen at the left hand end of the modelled chassis.

- The antenna is close to the flexi-circuits connecting the camera and the display: these couple noise into the receiver, particularly in the lower operating band;
- In use, the phone is often held around the hinge, exaggerating hand effects;
- Space constraints are usually very severe.

There is a further problem. The antenna centre-drives the chassis when the phone is open, end-drives it when t he phone is closed. A closed phone needs to retain enough sensitivity to maintain contact with the network; and many new phones operate in the closed position to receive e-mails and other data calls, or can be used for speech calls while closed. These problems point to the bottom end position as being as the most satisfactory electrical position for the antenna. Observation of the way in which users hold their phones shows there is considerable variability, both between the way one individual will hold different phones, and the way a particular phone will be held by various people. However there are indications that the weight of a phone, the distribution of weight along its length and the feel provided by surface contours and textures all have an influence in the way phones are held. If the phone feels right when held at the hinge, the bottom is clear of the hand and the head: again, the electrical performance is affected by non-electrical aspects of handset design.

OTHER CONSIDERATIONS

The battery of a modern phone occupies about 1/3 of its external surface – and does so for a closed clamshell phone. The presence of the battery almost always reduces the radiated signal. The battery functions electrically as a short-circuit stub approximately a quarter wavelength long and its presence and the manner of its grounding have a strong influence in the radiating currents flowing over the radiating external surface of the compound chassis.

The high current density in the flexi-circuit (fig. 5) and the strong influence of the inter-component reactance (fig 7) means that instability of the configuration of the flexi-circuit can give rise to large changes in antenna impedance. A production engineer trying to trace antenna variability by re-testing the antennas would simply fail to see the reason for the variability.

The design of conductive EMC (RFI) coatings clearly has a major impact on handset performance, and a better understanding of this can provide further gains in efficiency.

CONCLUSION

Especially in the lower frequency bands the whole handset functions as an antenna to provide the necessary bandwidth and efficiency. The efficiency of a handset is determined by a complex interaction of factors, many of which are determined by the styling and internal layout of components in the phone. The largest single cause of lost efficiency is a large mismatch loss at the antenna input and this paper has highlighted some of the most important handset parameters which interact with the antenna to control its impedance bandwidth. In the upper frequency bands the dimensions of the antenna are electrically larger and the best strategy is to decouple the handset from the antenna.

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