A high-performance five-band handset antenna using a dielectric feed

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Abstract

The economics of manufacture and requirements of international travellers are propelling the handset market towards to production of handsets covering five frequency bands occupying 826–960MHz and 1710–2170MHz. The paper describes an antenna providing high efficiency over these bands, together with measured data obtained from an antenna integrated into a complete handset.

1. INTRODUCTION

The proliferation of frequency bands available for mobile communications over the past decade has led to an increasing requirement for handsets capable of operation in multiple frequency bands. These typically include the GSM-850, GSM-900, GSM-1800, GSM-1900 and UMTS-2100MHz bands. The requirement arises from the needs of the international traveller, the widespread use of multiple-frequency overlay/underlay networks and the economics of manufacture. To avoid repetition of frequency limits, the bands 824–960MHz will be referred to as the Low Band and that from 1710–2170MHz as the High Band.

2. DESIGN CONSTRAINTS

It is well known that the bandwidth achievable from a handset antenna in the Low Bands is strongly dependent on the length of the handset, but the antenna designer must generally accept the length determined by the industrial design of the handset and can do relatively little to change it. In the High Band there is some dependence of bandwidth on length, but the input impedance of the antenna over a 27% bandwidth depends strongly on stray reactances associated with its construction and the configuration of its feed system.

The antenna was configured in a bar-phone with a groundplane dimensions 38 x 99mm and an available antenna volume of 17 x 38 x 7mm, although there was a 15mm-diameter semi-circular cut-out from this to accommodate the loudspeaker which lies 2mm below the top of the antenna plane.

The basic antenna configuration used is that of a dielectric-excited planar inverted-F antenna which is a further development of that previously described for four-band operation by the author and his colleagues [1]. The configuration of the antenna, shown in Fig. 1, is derived from the well-known configuration shown in Fig. 2. The capacitive top section of the antenna is divided into two sections which are resonant in the High and Low bands respectively. The antenna element is grounded at a point between the two resonant sections and it is capacitively fed at a point close to the ground point by means of a small dielectric puck. The dimensions of the puck are sufficiently small that its weight is entirely acceptable within the weight budget of the antenna – typically only around 1g. The puck is housed in a thermoplastic moulding (not shown in Fig. 1 for reasons of clarity) that also supports the antenna element and attaches the antenna to the underlying printed circuit board. The element was made as part of a flexible PCB with polyimide dielectric, but alternative constructions and materials such as pressed metal parts can also be used. A number of standard forms of connection are available and can be used in place of the simple mechanical pin shown in the simulation model.

The antenna is fed via the ceramic puck whose lower surface is metallised with high-conductivity silver paint fired at high temperature. As usual, the basic dimensions of the antenna are determined by the space available in the handset, so the parameters available for selection during the optimization of the design include:

- Puck: dimensions, permittivity and the distance between the upper surface of the puck and the antenna element; puck position;
- Antenna: shapes and dimensions of the branch arms resonating at the high and low bands and the position of the ground point relative to other features;
- Ground pin dimensions (changing its effective inductance);
- Input matching network (not shown, but generally comprising 2 or 3 components in a Pi- or L-network.

Connections to the feed point and groundplane were made with spring connections to simplify the assembly of the antenna into the handset.

The antenna was optimised by a judicious mixture of simulation and experiment; simulation helps in understanding the functions of the available parameters but cannot realistically be applied to a rigorous model of all the relevant features of the handset. As with many antenna optimization problems it is necessary to concentrate on the complex impedance (Smith Chart) and to create a compact impedance plot in which the impedance changes as slowly as possible with frequency over the bands of interest. The compact impedance characteristic is then centered on the Smith Chart with the aid of an appropriate matching network which combines lumped elements and transmission line elements.

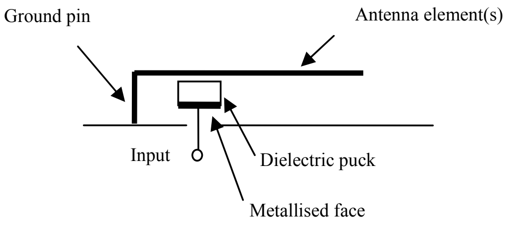

Fig. 1: Concept of a dielectric-excited PIFA
(Patent applied for, Antenova Ltd.)

Fig. 2: Simplified antenna layout from which the shape shown in Fig.1 was derived.

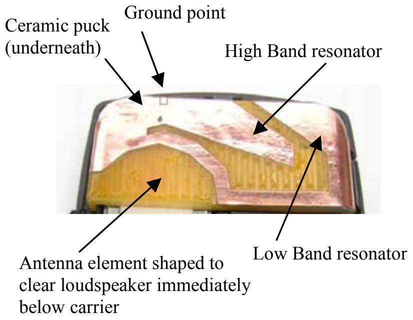

Fig. 3: View showing topology of the antenna

An important characteristic of the dielectric-excited PILA is that at low frequencies the input impedance is by nature capacitive. Variation of the distance between the top face of the puck and the top of the antenna allows adjustment of the coupling between the feed and the element, which strongly determines the shape and size of the impedance plot. The impedance characteristic in the upper band depends on the coupling between the puck and the resonators; it is also very sensitive to the value of the series stray inductance associated with the feed – by the use of the puck this is reduced to a very small value. The parallel capacitance between the lower face of the puck and the groundplane is significant for antennas with very limited height, but was not detrimental in the present design.

Having obtained the most compact impedance characteristics across all the operating frequency bands, the operating VSWR was reduced by careful design of the input matching networks to center the impedance curves at both groups of operating bands. The matching networks were simulated using the component manufacturer's models for the loss resistances and strays associated with the real matching components. This rigorous method of design allows the achievement of an optimum-efficiency solution across all the frequency bands of interest. This technique does not necessarily provide the same solution as one aiming only to provide minimum input VSWR because the efficiency increment obtained by improving the input VSWR may (at some frequencies at least) fail to offset the loss of efficiency caused by increasingly lossy matching components.

The technique described can be used with antennas mounted above a continuous groundplane (the main handset PCB), but to obtain the highest possible bandwidth a small region of the groundplane below the puck is sometimes cut away; the antenna whose performance is reported here was mounted in an existing commercial handset, so in this case it was not possible to modify the original groundplane significantly.

The components of a handset that lie close to the antenna have a considerable – and usually negative – effect on the performance of an antenna. To reduce the extent to which RF currents were coupled to the nearby loudspeaker, inductors (with a value of a few 10s of nH) were placed in series with both its terminals.

3. RESULTS

The performance of the antenna was measured in an anechoic chamber which is well characterised and is know to produce results in good agreement with other measurement systems. Its terminal efficiency (including loss from all sources including mismatch loss) is shown in Fig. 4 where it will be seen that remarkably consistent performance has been achieved across both very wide groups of frequency bands.

The antenna was measured in a complete and assembled handset with speaker, camera, display and other associates hardware. The polarization components referred to in Fig. 4 relate to the orientation of the illuminating horn; measurements were made with the long axis of the handset in the horizontal plane. As usual the polarization in the low band is strongly aligned with the long axis of the handset but in the high band it has components in both planes.

It will be seen in Fig. 5 that the input return loss was adjusted to provide a larger value near the bottom edge of the low band in order to make the efficiency more uniform across this band.

The antenna design reported here has exceptionally stable performance over a pair or very wide frequency bands. The use of capacitive coupling may be compared with the probe feed developed by Luk [2] to feed a conventional patch antenna. The use of the puck reduces the series feed inductance, allowing a further increase in bandwidth. The feed system creates opportunities to provide a very broadband input impedance and this allows the achievement of high terminal efficiencies even when the antenna is mounted in a well-configured commercial handset.

It has been suggested that it is simply not possible to reduce the Q-factor (and so to increase the bandwidth) of a very small antenna. However, as has been shown elsewhere [3, 4] the radiation from a handset is created by currents flowing in the chassis of the handset and this creates a rather more com-

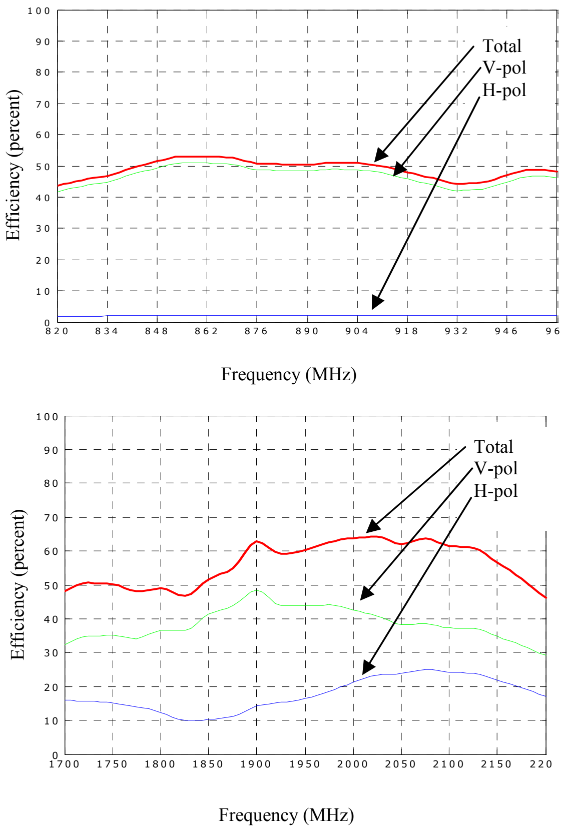

Fig. 4: Measured terminal efficiency of the handset in the low bands (above) and high bands (below).

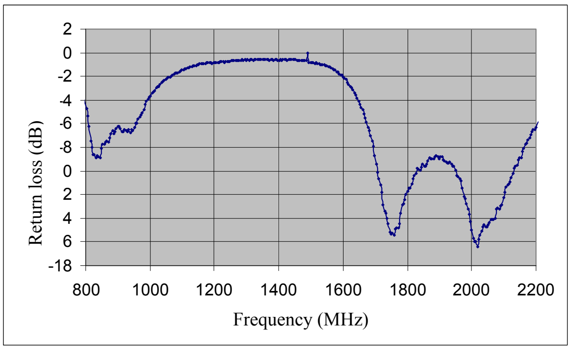

Fig. 5: Measured input return loss

plex relationship between the dimensions of the antenna itself and the effective dimensions of the radiating structure.

The impedance bandwidth derives from a complex interaction between the impedances presented to the currents flowing in the groundplane together with that encountered by currents flowing in the antenna – put another way the equivalent circuit is much more complex than a lossy series-resonant L-C combination.

4. CONCLUSION

The use of dielectric excitation of an inverted-F antenna can create wider impedance bandwidths and consequent improvements in efficiency compared with conventional directly connected feeds. It has been shown that even allowing for the realities of the environment of a real handset a 5-band antenna is a practical proposition. The fundamental bandwidth constraints for an unbalanced handset antenna (operating over the low bands) are complex, especially when use is made of matching and impedance compensating circuits external to the antenna. As yet there appears to be no definitive limit and the typical practical antenna engineering practice of finding new solutions to old problems is continuing to yield ever greater performance from small compact handsets.

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