Diversity Arrangements for Internal Handset Antennas

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ABSTRACT

This paper studies various diversity arrangements for handset antennas at about 1900 MHz by means of measurements and simulations. The antennas used in the diversity arrangements are radiation coupled dual-L antennas (RCDLA), which are strong candidates for internal antennas for mobile terminals. The measurements show that good pattern and polarisation diversity can be obtained with the studied diversity arrangements. It is also shown that the position of the antenna on the case strongly affects the magnitude of the detuning effect that the hand of the user causes. The problems caused by the hand of the user can be mitigated by using diversity antennas at the mobile.

I. INTRODUCTION

Internal antennas are an attractive alternative for handset antennas. The strongest candidates for internal antennas seem to be found from microstrip antennas [1], PIFAs [2] or radiation coupled dual-L antennas [3], [4]. This paper concentrates on the latter, as they offer a wide bandwidth as well as a small size. The DCS1800 system requires a bandwidth of 9.5% at about 1800 MHz.

Traditional monopole and helical antennas have an omnidirectional radiation pattern. Therefore a large part of the radiated power is lost in the head and hand of the user. This leads to a shorter lifetime of the battery as well as a decrease in the link margin. By using a suitably mounted planar antenna [5], [6] these problems can be alleviated, and the discussion of possible biological effects of electromagnetic fields elegantly avoided. The conducting case, which acts as a ground plane, directs the radiation away from the head of the user.

To improve the link quality, diversity can be used at the mobile also. It can be implemented as space, polarisation or pattern diversity or as a combination of these. In this paper three different diversity arrangements are discussed.

Internal antennas are more likely to be affected by the hand of the user than *external* antennas. We will show that a diversity antenna can be used to solve this problem as well.

II. RCDLA

The RCDLA is studied here as it offers enhanced bandwidth, improved matching capabilities, small size and high gain. The RCDLA consists of two narrow "L"-shaped metal plates a fraction of a wavelength above the conducting case depicted in Figure 1. The plates are short-circuited at one end and are slightly wider at the other end, at the tips of the antennas. There is a narrow slot between the antenna elements. Only one of the elements is fed from a coaxial cable beneath the case, while the other one is radiation coupled. The radiation coupled element is slightly shorter. The enhanced bandwidth can be attributed to the slightly different resonant frequencies of the elements. Currents in the antenna elements can flow in three dimensions; along the elements, in the feed and the short-circuited plates as well as across the widened tips. Therefore the radiation patterns show relatively high levels in all planes for both polarisations. A handset antenna can be held at any angle and the polarisation of the incoming signal can be arbitrary in a multipath environment. Hence sensitivity to both polarisations in all planes is desirable.

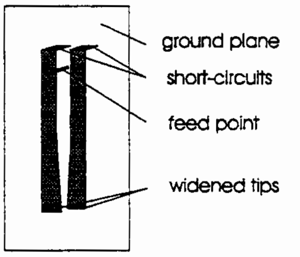

Fig. 1 Antenna elements of a RCDLA.

The RCDLA can be mounted on the case in various ways. The mounting strongly affects the matching, bandwidth and radiation pattern of the antenna. The back-mounted RCDLA, which is shown in Figure 2a, has been previously discussed in [6]. By mounting the RCDLA at the back side of the case and leaving some distance between the antenna elements and the edges of the case, a directive radiation pattern can be obtained. The amount of directivity increases when the antenna is positioned further away from the edges of the case. The drawback of this mounting position is its smaller bandwidth. It is also possible that the user grips the handset so that the antenna

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is partly or completely covered by the hand and hence power is lost in the hand.

Another possibility for mounting the RCDLA is to position it on top of the case, according to Figure 2b. This mounting position has been analysed in [4]. When the RCDLA is top-mounted the case is no longer between the antenna and the head of the user. Therefore the radiation pattern is not directed away from the head of the user. On the other hand a far better bandwidth can be obtained. It is also less likely that a top-mounted antenna will be completely blocked by the user. Therefore these two different mounting positions can be used to achieve different goals.

III. DIVERSITY ARRANGEMENTS

When using diversity at the mobile the uplink and downlink have to be considered separately. In the downlink it is possible to use conventional combination techniques [7]. One simple method is to use selective diversity combining where the strongest signal or the signal with the smallest BER is selected. Of course it is also possible to utilise received signals from both antennas by using e.g. maximum ratio combining.

In the uplink there is no a priori knowledge about which signal might reach the basestation with better quality. But one way to gain from two antennas is to choose the antenna that is not covered by the hand. This can be checked by determining the reflection coefficient on the feed line to the antenna. As shown in Chapter V the matching of the antenna changes significantly when the antenna is covered by the hand of the user. In this case the other antenna, less affected by the presence of the hand, should be used for transmitting.

Some internal diversity arrangements were discussed in [3]. In the present paper the diversity arrangements depicted in Figure 2 are studied. The monopole antenna of Figure 2a was chosen as a reference antenna as whip antennas are widely used in handsets.

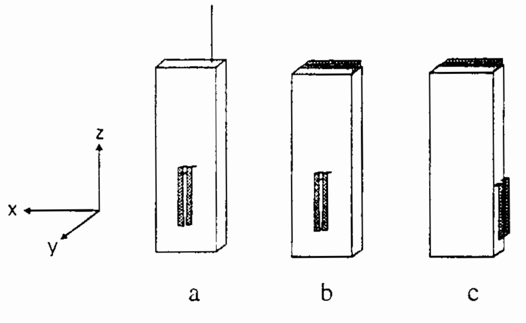

Fig. 2 Diversity arrangements using a) monopole and back-mounted, b) top-mounted and back-mounted and c) top-mounted and side-mounted antennas.

The diversity antennas were positioned so that the largest possible decorrelation can be achieved. As the size of the handset is normally fairly small the antennas have to be placed on opposite sides of the case, as far away from each other as possible. In order to obtain a large pattern and polarisation diversity we place the antennas on faces that are perpendicular to each other.

The question where the user most likely grips the handset has to be carefully considered. If a back-mounted RCDLA is used as one antenna, it may be wise to choose a top-mounted RCDLA as the second one. Hence it is possible to ensure reception even if the user's hand is blocking the back-mounted RCDLA. On the other hand the back-mounted RCDLA can be used whenever it is not completely blocked, as it directs the radiation away from the head of the user. If it is not fully covered by the hand less power is lost due to the presence of the user.

IV. INVESTIGATED ANTENNAS

The antennas were mounted on a conducting case of dimensions 120 mm long, 39 mm wide and 11 mm thick. The size was chosen to be approximately that of present handsets. The antennas were fabricated from a 0.25 mm thick metal sheet and the case from a 0.30 mm thick metal sheet. Each antenna was fed by a separate coaxial cable from inside the case.

The antennas have slightly different dimensions and frequencies due to the different mounting positions. All antennas were optimised and tuned separately. The back-mounted RCDLAs of Figure 2a and 2b have a smaller bandwidth of about 130 MHz at a centre frequency of about 1900 MHz. The top-mounted RCDLAs of Figures 2b and 2c have a larger bandwidth of above 200 MHz at a centre frequency of about 1870 MHz. The side-mounted antenna of Figure 2c is closer to the top-mounted antenna in behaviour due to the mounting position. It has a bandwidth of 161 MHz at a centre frequency of 1860 MHz. The conventional monopole antenna shows the largest bandwidth of above 500 MHz at a centre frequency of 1900 MHz.

Only the top-mounted RCDLA fully satisfies the bandwidth requirement of the DCS1800 system. As the bandwidth we take a VSWR $\leq$ 1.92, which is equal to a $S_{11} \leq -10$ dB. The other RCDLAs do not satisfy the bandwidth requirement, of a return loss larger than 10 dB, over the whole DCS1800 frequency band. This is, however, less critical in a diversity system where the second antenna can be used for the frequencies, for which the matching of the antenna is not good enough.

V. MEASUREMENTS OF THE EFFECT OF THE HAND

The hand of the user affects the matching and centre frequency of the antenna as well as the coupling of the antenna elements significantly. The magnitude of the effect depends on how much of the antenna is covered and from which side it is covered [8]. Therefore it is important to place the antenna so that the user is likely to cover the antenna from the side that affects the performance less.

Figure 3 shows the positions of the hand during the measurements.

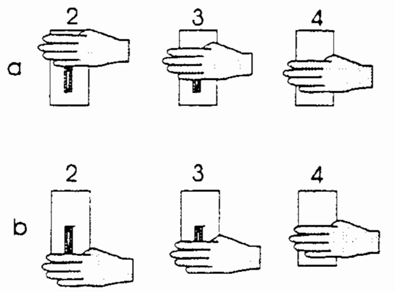

Fig. 3 Positions of the hand during the measurements from the side of a) the short-circuit and b) the tips.

In the measurements we used a phantom hand that was made of a rubber glove filled with a 45% sugar-water solution with gelatine added. During the measurements the handset was inside a thin plastic case. The plastic case had a small detuning effect on the antenna.

In the following Figures curve 1 always illustrates the matching of the relevant antenna with no hand. Curves 2, 3 and 4 refer to the position of the hand according to Figure 3a or 3b. For the back-mounted RCDLA the measured results in Figure 4 show the effect when the hand is covering the antenna from the side of the short-circuit according to Figure 3a. Curves 2, 3 and 4 show the effect when the hand is at the short-circuit, covering half of the antenna and covering it completely. The effect is relatively small. The centre frequency did not change before the antenna was covered completely and the matching remained good.

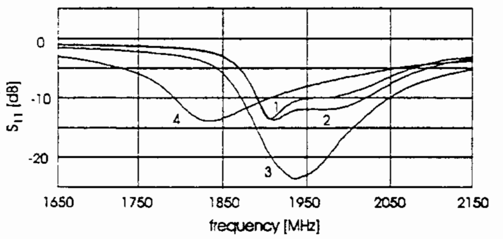

Fig. 4 Effect of the hand on the *back-mounted* antenna from the side of the *short-circuit*.

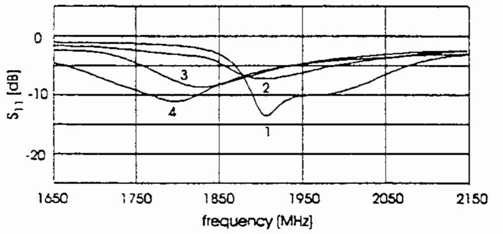

Fig. 5 Effect of the hand on the *back-mounted* antenna from the side of the *tips*.

Figure 5 illustrates the measured results when the hand was brought on top of the back-mounted RCDLA according to Figure 3b. Curves 2, 3 and 4 illustrate the effect when the hand is at the tips, covering half of the antenna and covering it completely. Approaching the tips the effect of the hand is significantly more harmful than when approaching the short-circuit. The matching is strongly affected by just bringing the hand to the tips, not covering any of the antenna. Covering the antenna fully or partly also changes the centre frequency significantly.

The back-mounted antennas of Figures 2a and 2b have been mounted according to these measurement results. As the user most likely holds the handset in the middle of the case the short-circuit is pointing towards the centre of the case and the tips away from the centre.

Similarly, the optimal orientation of the side-mounted RCDLA of Figure 2c can be defined. The results are illustrated in Figure 6 for approaching the short-circuit according to Figure 3a. Curves 2, 3 and 4 show the effect when the hand is at the short-circuit, covering half of the antenna and covering it completely. The effect is relatively small unless the whole antenna is covered.

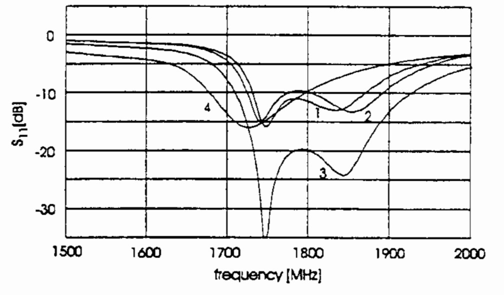

Fig. 6 Effect of the hand on the *side-mounted* antenna from the side of the *short-circuit*.

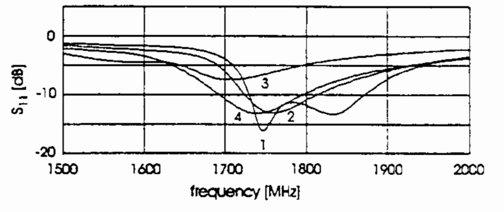

Fig. 7 Effect of the hand on the *side-mounted* antenna from the side of the *tips*.

Figure 7 shows the measured results for the side-mounted RCDLA when the hand was approaching the antenna according to Figure 3b. Curves 2, 3 an 4 show the effect when the hand is at the tips, covering half of the antenna and covering it fully. The effect of the hand is again more harmful when approaching the tips than when approaching the short-circuit. Therefore the side-mounted antenna was also placed so that the short-circuit pointed towards the centre of the case. The effect is, however, less severe than for the back-mounted antenna. This is due to the fact that the antenna was only covered completely from one side, whereas the other side was only covered by the thumb.

VI. RADIATION PATTERNS

The radiation patterns were measured in the precision anechoic chamber of the Austrian Research Centre Seibersdorf. During the measurements only one antenna was fed, while the other one was terminated with 50 Ω.

All patterns of all antennas are normalised to the same received maximum power level, which was obtained by the *top-mounted* RCDLA. All measured RCDLAs showed power levels of at least equal to that of the monopole antenna.

If we compare the patterns of two diversity antennas in the same polarisation, in the same pattern plane, we assess pattern diversity. If we compare the dominant polarisations of two diversity antennas, in the same pattern plane, we speak about polarisation diversity.

The measured radiation patterns for the antennas of Figure 2a are shown in Figure 8 for the monopole and in Figure 9 for the *back-mounted* RCDLA. Evidently good polarisation diversity can be achieved by using this antenna combination. Also the nulls and notches of the two antennas point at different angles in space in most cases. Therefore the diversity antenna also shows good pattern diversity. The *back-mounted* RCDLA radiates less towards the head of the user, as can be seen from the yz- and xy-plane radiation patterns of Figure 9.

The measured radiation patterns for the *top-mounted* RCDLA are shown in Figure 10. Comparing those with the patterns of the *back-mounted* RCDLA, the polarisation and pattern diversity of the antenna arrangement of Figure 2b can be assessed. The polarisation diversity is good in all planes. Also considerable pattern diversity can be achieved by using this antenna configuration. However, the *top-mounted* antenna does not direct less radiation towards the head of the user.

The measured radiation patterns for the *side-mounted* RCDLA are shown in Figure 11. Studying the patterns of the *top-mounted* and *side-mounted* RCDLA, the performance of the antenna arrangement of Figure 2c can be evaluated. Again good polarisation diversity can be obtained. The pattern diversity of this configuration is also fairly good. In this case the antennas do, however, not show any reduced radiation towards the head.

Before fabricating the RCDLAs they were simulated with a workstation version of AntCAD [4], a simulation tool merging the power of NEC2 and AutoCAD™ programmes. As a comparison for the measurements the simulated patterns for the *top-mounted* RCDLA are shown in Figure 12. The simulated and measured radiation patterns agree fairly well. The small differences are caused by the slightly different dimensions of the simulated model and the measured antenna. Some of the differences are also caused by the feeding cables of the handset antennas during the measurements.

VII. CONCLUSIONS

Terminal antenna diversity offers a possibility to mitigate the problem of the antenna being covered by the hand. Also remarkable pattern and polarisation diversities of the studied diversity arrangements demonstrated that diversity can be effectively used to improve low levels of the received signal due to notches in the radiation patterns. With the RCDLA, relatively high power levels for all polarisations in all planes ensure good reception independently of the polarisation and incidence angle of the incoming signal. The RCDLA can also provide a large bandwidth or direct radiation away from the head of the user depending on the mounting position on the case. The effect of the hand on the matching and centre frequency of the RCDLA was shown to be smaller from the side of the short-circuit. Therefore the short-circuit was placed closer to the centre of the case to minimise the detuning effect as well as power absorption caused by the hand.

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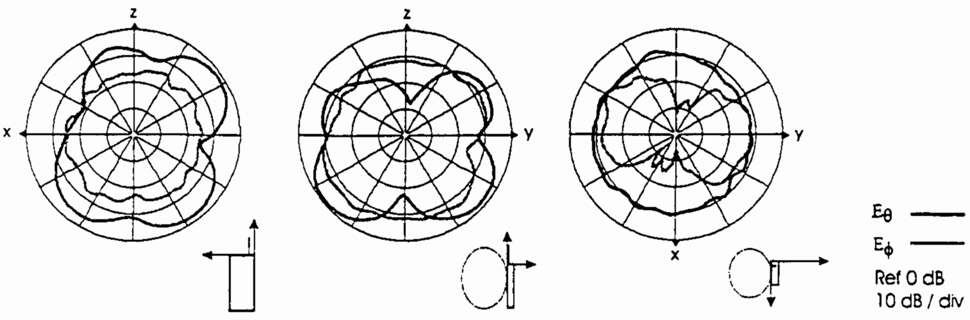

Fig. 8 Measured radiation pattern of the monopole antenna (2a) at 1900 MHz.

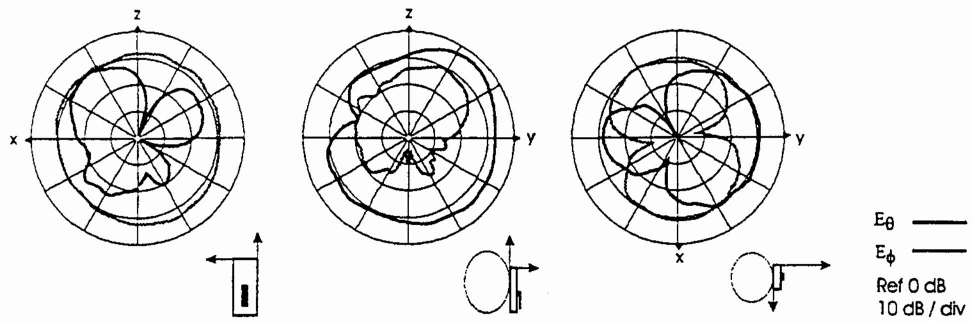

Fig. 9 Measured radiation pattern of the *back-mounted* RCDLA (2a & 2b) at 1902 MHz.

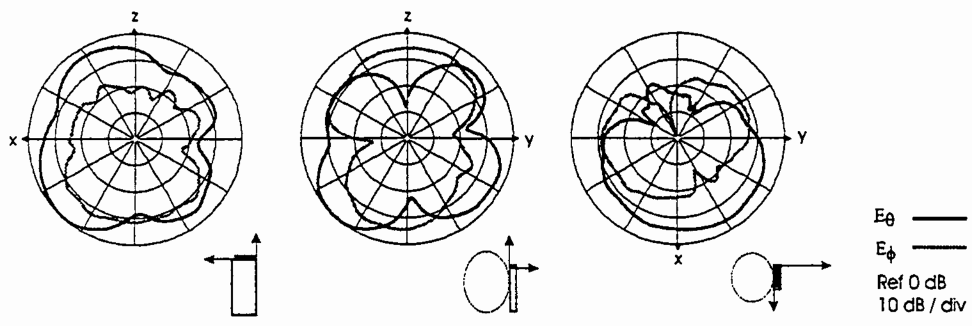

Fig. 10 Measured radiation pattern of the *top-mounted* RCDLA (2b & 2c) at 1870 MHz.

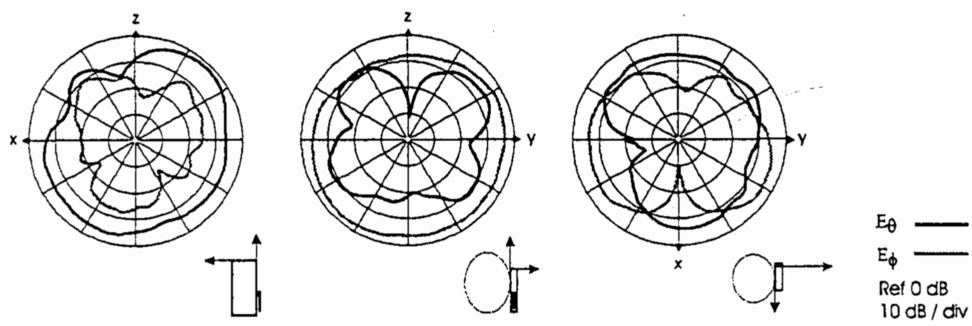

Fig. 11 Measured radiation pattern of the *side-mounted* RCDLA (2c) at 1860 MHz.

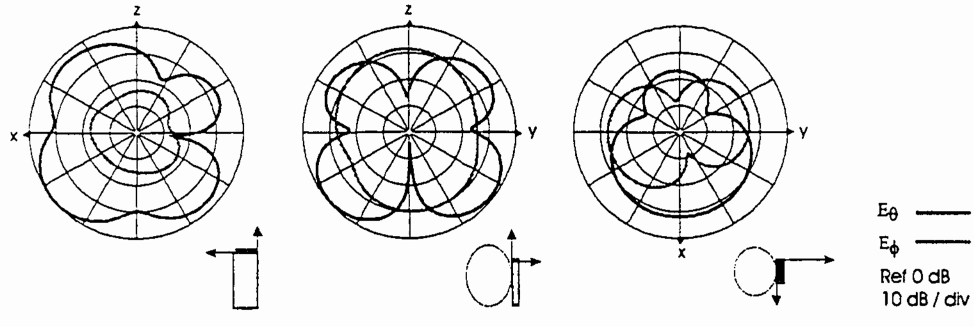

Fig. 12 Simulated radiation pattern of the *top-mounted* RCDLA (2b & 2c) at 1870 MHz