Dual Band Base Station Antenna Systems

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Abstract— **An analysis of the possibilities of using dual band antennas in cellular radio is presented. Results from simultaneous measurements at 900 MHz and 1800 MHz are presented and analyzed. Based on the measured results, a dual polarized, dual band base station antenna has been designed. Such an antenna proveides the opportunity to replace a 4 antenna space diversity installation with a single antenna, thereby reducing costs and tower space.**

I. Introduction

The demand for antennas for mobile wireless applications has increased dramatically over the last 10 years. Today we have a number of land and satellite based systems for wireless communications using a wide range of frequency bands. Not only do we see an increase in the number of subscribers in the different systems but also a demand for dual band equipment capable of handling two or more systems. Due to the capacity problems encountered today in the AMPS (824-894 MHz) and GSM (880-960 MHz) systems in Europe and North America, many operators have acquired a license for the 1900 MHz PCS or 1800 MHz DCS bands respectively.

Since a major problem during the deployment of a cellular radio network is to find suitable sites for the base stations, one can expect these operators to use their existing sites for the new base station wherever possible. In an urban or sub-urban environment, the cost of installation of feeder cables and antennas as well as the overall need to reduce the number of antennas then makes a dual band antenna attractive. One way of implementing this would be to replace an existing GSM or AMPS antenna with a dual band GSM/DCS or AMPS/PCS antenna. Such dual band operation is perhaps more useful for the GSM/DCS operators where the protocols of the two systems are close to identical [1], and we will therefore restrict the discussion to this case.

A concern regarding dual band wireless systems is the different propagation in the two bands. The antenna gain of a hand-held mobile terminal is practically 0 dB in both bands due to its omnidirectional pattern, and the gain of the base station antenna is at best 3 dB higher in the upper band if the same vertical length antenna is used in both bands with the same azimuth coverage. This means that even in a free-space scenario, we can expect 3 dB higher path loss in the 1800 MHz band than in the 900 MHz band. However, the difference in path loss for the two bands in a real world radio environment is found to be rather in the order of 10 dB [2], both in simulations and measurements. Depending on how a dual band system is set up this difference may or may not be crucial. If one seeks to co-site the two bands and use identical cellplanning, the smaller this difference is, the higher capacity is provided by the new 1800 MHz channels. As long as the major part of the cell area is covered by the new 1800 MHz channels, traffic may be moved to these channels thus decreasing the load on the 900 MHz channels. It may also be possible to substantially reduce the signaling in the network by allocating the Broad Cast CHannels (BCCH) in only one band. On the other hand, if additional capacity is needed throughout an area, the need for similar coverage is higher.

The use of diversity reception is essential in mobile radio to combat fading and we have seen an increased interest in the use of polarization diversity [3–5] at the base station instead of the traditional space diversity. This reduces the bulky space diversity installation to a single antenna installation. Since the motivation for a dual band antenna is primarily to reduce the number of antennas installed, the full potential of a dual band antenna system calls for dual polarization operation as well. A dual polarized, dual band antenna makes it possible reduce a four antenna installation two a single antenna installation and is therefore very attractive for the operator. If two band-separating filters are placed at the base station, it is also possible to use only two feeders instead of four. This means reduced cost, wind load, weight and installation time.

In this paper we first present simultaneous measurements of the path loss at 900 MHz and 1800 MHz. We are primarily interested in the statistical properties of the propagation at different distance since this is the main property related to the design of a dual band antenna, in terms of both vertical and horizontal pattern. Therefore we analyze the measured data statistically as a function of the distance between the base station and the mobile rather than in terms of point-to-point propagation.

We then present a dual band, dual polarized antenna designed for use in an urban or sub-urban environment. Based on the conclusions from the measurements mentioned above, the antenna is designed for maximum gain in both bands.

II. Dual Band Propagation Measurements

We performed a set of down-link measurements in a sub-urban area in Täby which is located north-east of Stockholm, Sweden. The base station antennas were placed on an 8 m tower on top of a 30 m high-rise residential building. The building is located on a hill which places the antennas some 50 m above the surrounding terrain. Figs. 1-2 shows the view north and east from the base station site. The antennas were directed at a compass bearing of 340° and Fig. 3 shows a map of the measurement area. This sub-urban area is characterized by mostly residential houses,

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Fig. 1. View north over most of the measurement area in Täby, Sweden.

Fig. 2. View west over the measurement area also showing the antenna site and two of the authors.

some higher apartment buildings next to the Täby shopping mall and fairly low rolling hills. There is a significant amount of vegetation present, mostly in the form of trees. The measurements were performed in June so we have maximum blockage by the foilage and therefore only line-of-sight in a few locations in the area.

On the tower shown in Fig. 2, we mounted two vertically polarized base station antennas, one for each frequency band. Both antennas had a horizontal half-power beamwidth of 65° and a vertical pattern with a half-power beamwidth of 14° and 15°, respectively, and an electrical down-tilt of 6°. The gain of the antennas were 15.5 dB and 15 dB respectively. Given the base station antenna height of 50 m above the surrounding terrain this places the maximum of the vertical radiation pattern at a distance of 480 m. Furthermore the lower 3 dB point is at 220 m and the upper is above the horizon. The maximum distance in these measurements is 3700 m corresponding to an elevation of -0.8°. Thus the complete measurement area falls within the main beam in elevation and there is no concern that we measure path loss to a point which is in a null in the pattern.

The base tranciever station (BTS) transmitted a power of 12 W in GSM and 18 W in DCS. On the receive end there were two vertically polarized roof antennas mounted on a car. The data was collected using two TEMS units [6], each connected to a GPS (Global Positioning System) unit. One TEMS unit was used for GSM 900 MHz and one for DCS 1800 MHz. The TEMS units were calibrated at the frequencies of interest over the range from -35 dBm to -100 dBm. It turned out that the 1800 MHz TEMS showed -4 dB relative the true value in all cases and this error was accounted for in the following data analysis. Each TEMS unit was locked onto a TRX-channel and measured the received power 2-3 times per second. The car traveled practically every street in the measurement area as indicated by the plot of the individual measurement points in Fig. 4. The measurement locations are actually determined by the possibility to trace a call at 1800 MHz, and the route in

Fig. 3. Map over the measurement area. The BTS is located at the 'x' close to the lower edge of the map.

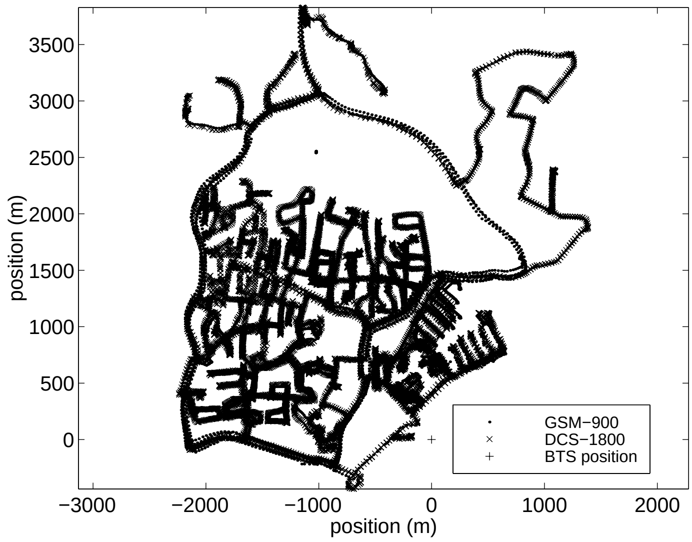

Fig. 4. Location of the individual measurement points.

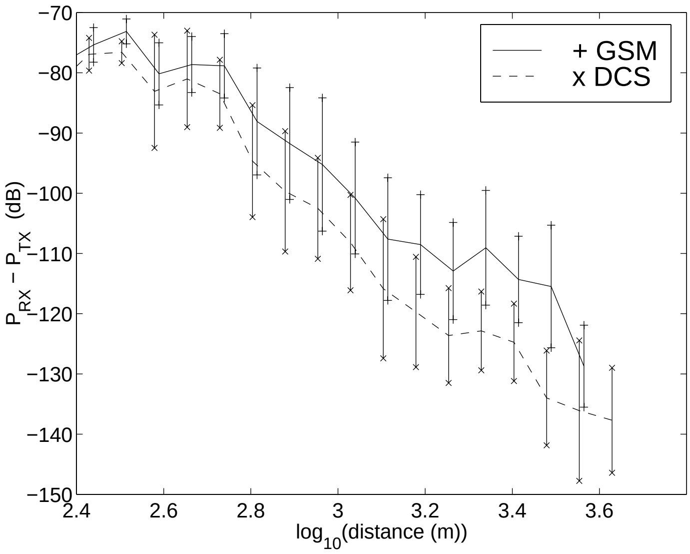

Fig. 5. Average path loss $P_{RX} - P_{TX}$ at GSM 900 MHz and DCS 1800 MHz as a function of distance from the base station. The average ± one standard deviation is shown for each data group. The different radiated power due to the horizontal radiation pattern of the base station antennas has been compensated for and the values assume a 15 dB base station antenna gain.

Fig. 4 therefore shows the effective cell size in this band. As we can see from a close look in Fig. 4, another source of error was the two GPS units. Although the constant biased error was accounted for by reading the instrument at a known loacation, the position found from the instruments still differs by up to 50 m. This is true also for measurements at different time on the same street with the same instrument. However, for the purposes of the path loss vs. distance analysis in this paper the error is still neglible.

A total of 38 725 GSM-900 and 35 446 DCS-1800 data were collected. The azimuth angle from the base station antenna to each point was calculated so that the received power could be adjusted to account for the known azimuth pattern of the antenna. In order to facilitate the further analysis of the data we grouped the data for each 0.075 of $\log_{10}$ of the distance to the base station. This produced 18 and 19 data groups respectively. We then compenstaed for a feeder loss of 1.3 dB at 900 MHz and 1.8 dB at 1800 MHz. Finally we calculated the path loss as $P_{RX} - P_{TX}$ and for each data group the mean and the standard deviation is shown in Fig. 5. The 1800 MHz values have been shifted by +0.5 dB to ralate the results to same gain as the 900 MHz values (15 dB). Note that due to extreme line-of-sight conditions close to the BTS the received power actually increased with distance the first few hundered meters; these data are not shown in Fig. 5. The standard deviation of the data groups is acceptable and ranges from 2 dB to 11 dB for GSM-900 and 1.8 dB to 11.5 dB for DCS-1800. For most data groups the standard deviation is close to the 8 dB mentioned in [7].

A linear fit to all the data yields a increase in path loss of 48 dB/dec for GSM and 55 dB/dec for DCS. This loss is considerably higher than the 30-40 dB/dec found for sub-urban and urban environments in [7, 8]. A possible cause for the high path loss is the presence of trees and foilage throughout the measurement area as seen in Figs. 1,2. In [7] it is stated that foilage could provide a total path loss of up to 60 dB/dec at 800 MHz. If we also consider a foilage loss depending on the frequency as f^4 [7] we have an explanation for the larger attenuation at 1800 MHz compared to 900 MHz. Alternatively, we can use the numerical analysis in [9] were the tree-specific attenuation for vertically polarized waves is calculated to be 0.7 dB/m at 900 MHz and 1.4 dB/m at 1800 MHz. Since the propagation distance through trees increases with distance due to more grazing incidence towards the mobile, this explains why the difference between the average path loss for 1800 MHz and 900 MHz increase from 3 dB to 12 dB over a decade in Fig. 5.

III. A Dual Polarized Dual Band Panel Antenna

As seen in the previous section, the path loss in a sub-urban environment can be 10-15 dB higher at 1800 MHz than at 900 MHz. In some instances we might therefore need all the extra antenna gain possible at 1800 MHz compared to 900 MHz. We have developed a dual polarized, dual band panel antenna for the 872-960 MHz and 1710-1880 MHz frequency bands. The polarization is ±45° linear which is desirable in diversity reception since it provides equal mean power on the two branches. The antenna is a sector antenna for a cellular network and the desired beamwidth is 72° with respect to -3 dB total power.

A. Antenna Design

The antenna element is an aperture coupled stacked patch with the symmetry needed for good dual polarization operation as described in [10] but with the apertures aligned ±45° to the vertical axis. The elements thus provide slant ±45° linear polarization. The antenna consists of

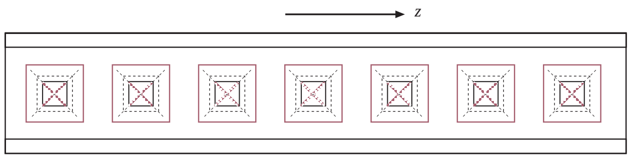

Fig. 6. Schematic of the antenna array showing the 7 dual polarized elements.

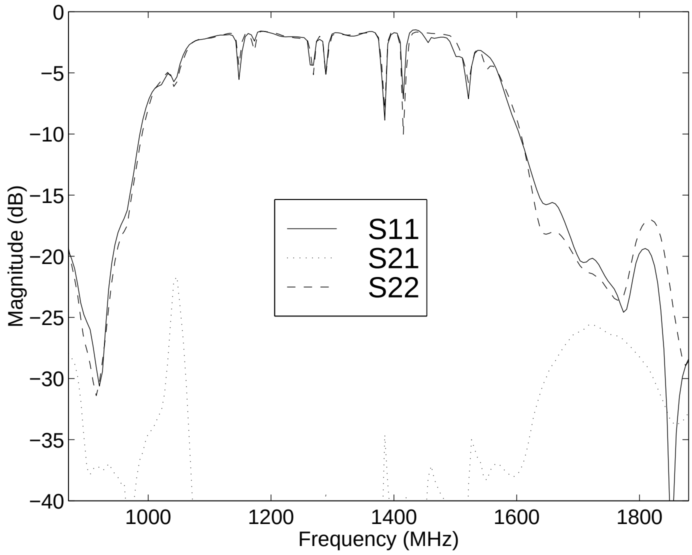

Fig. 7. S-parameters for the antenna array.

7 such elements arranged in a linear array. There is no displacement of the elements from the centerline which allows for symmetrical radiation patterns, low cross-polarization, and good tracking between the two channels. Fig. 6 shows the schematic of the antenna. The dimensions are 1200 x 300 x 110 mm. The elements consists of three stacked patches with cross-shaped aperture in the groundplane and in the middle patch.

We use a dual-band feed network that minimizes the complexity of the antenna as well as the feed losses. The feed network consists of reactive power dividers in microstrip technology and 50Ω coaxial and microstrip transmission lines. The antenna has zero electrical down-tilt; i.e. the beam peak is at zero degrees elevation. The spacing between the elements of 165 mm is approximately one wavelength in the 1800 MHz band.

B. *Antenna Measurements*

We have measured the antenna with respect to S-parameters, radiation properties and gain.

Fig. 7 shows the return loss and isolation of the two antennas. The return loss for both antennas and both bands is greater than 17 dB. The isolation is greater than 26 dB.

Figs. 8-9 shows the co- and cross-polar radiation pattern in the horizontal plane at 915 MHz and 1785 MHz. The cross-polarization is very low, typically around -23 dB, except for one of the channels at 1785 MHz. Since

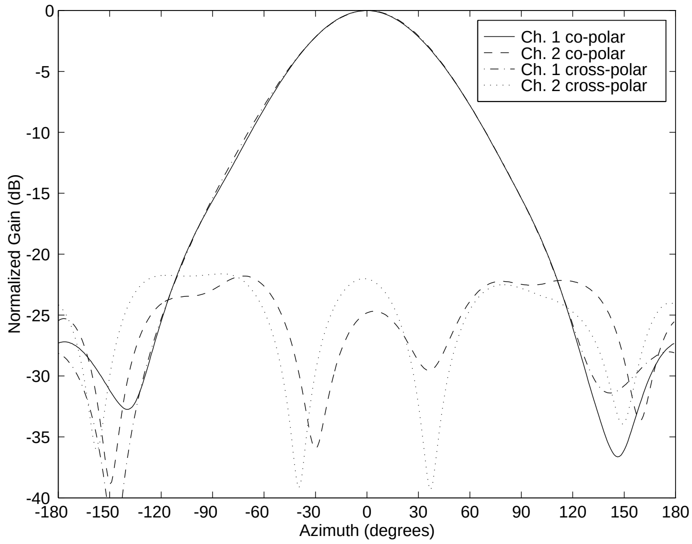

Fig. 8. Radiation pattern in azimuth at 915 MHz.

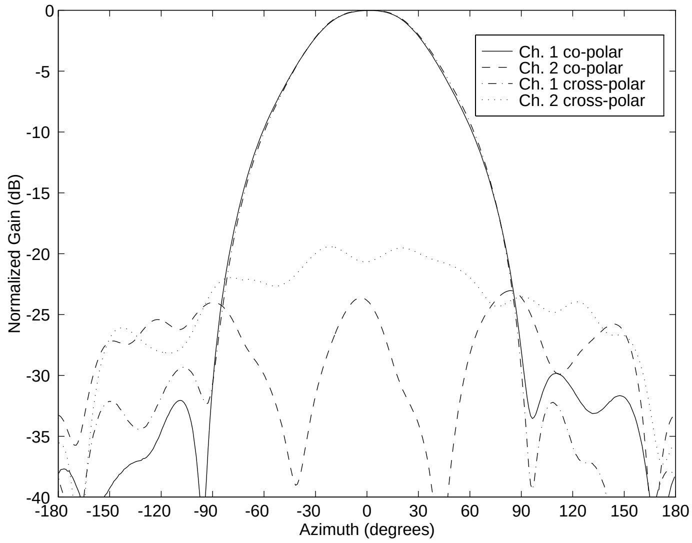

Fig. 9. Radiation pattern in azimuth at 1785 MHz.

the design is symmetric we expect similar performance for both channels and we therefore think that a likely cause of the somewhat higher cross-polarization of one channel is measurement error. The tracking between the channels in azimuth is almost perfect. The radiation pattern falls off more rapidly in the upper band both the tracking between the bands is still very good down to the -3 dB level. The beamwidth at 915 MHz is 71.5° and at 1785 MHz it is 69°. The deviation from these values over the two bands is limited to ±3° and ±2° in the 872-960 MHz and 1710-1880 MHz bands respectively. In both cases this is less than the spread due to the different electrical size of the aperture over the frequency band.

Since the antenna is intended for polarization diversity reception it is important to assess how it performs as a sensor for two orthogonal polarizations. Following [11, 12] we have calculated the far-field coupling between the two

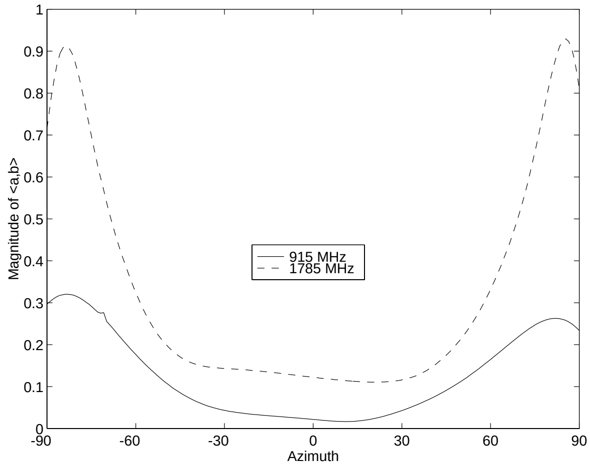

Fig. 10. Far-field coupling $\langle \mathbf{E}_a, \mathbf{E}_b \rangle / (|\mathbf{E}_a||\mathbf{E}_b|)$ in azimuth at 915 MHz and 1785 MHz.

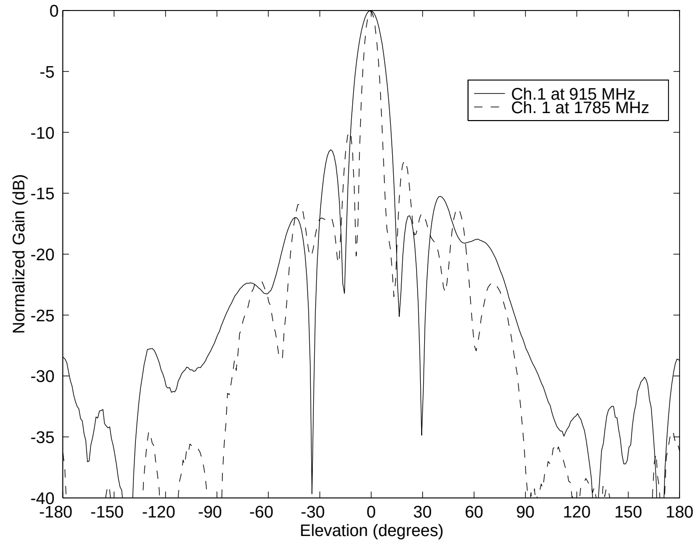

Fig. 11. Radiation pattern in elevation for channel 1 at 915 MHz and 1785 MHz.

channels. This coupling is defined for the electrical far-fields of channels a and b as:

$$\frac{\langle \mathbf{E}_a, \mathbf{E}_b \rangle}{|\mathbf{E}_a||\mathbf{E}_b|}$$

As shown in [11] this coupling is a measure of the power correlation of the output signals from the antenna (Note that for this type of antenna which is symmetrical with respect to the vertical axis, an equivalent measure would be how equal the vertical and horizontal polarization patterns are in azimuth). Fig. 10 shows this coupling at 915 MHz and 1785 MHz. Within the $\pm 45°$ sector the coupling is below 0.33 and the power correlation is thus below 0.1 for an un-polarized Rayleigh case [11]. The low correlation makes the antenna a good candidate for a polarization diversity sensor.

The elevation pattern suffers somewhat frorn the fact that the physical spacing between the dual band elements is identical at both bands. Since this 165 mm spacing is approximately one wavelength in the 1710-1880 MHz band we get a grating lobe. This grating lobe is not seen in the elevation pattern in Fig. 11 since there is no beam tilt, but it is a cause of concern for a down-tilt antenna. Although not evident from Fig. 11 it is quite possible to achieve a good upper sidelobe suppression and null-fil below the main beam. The latter is probably much desired for this type of antenna since a deep null in the 1800 MHz band would result in very different signal strength received for mobile stations positioned within the main beam in the 900 MHz band.

The gain was measured to 14.4-15.1 dB and 16.9-17.1 dB in the 872-960 MHz and 1710-1880 MHz band respectively. We believe that some gain is lost in the use of nylon spacers in this prototype.

IV. Discussion and Conclusions

Our investigation of the propagation characteristics in a sub-urban cell indicates that the path loss at 1800 MHz could be 10-15 dB higher than at 900 MHz. A contributing factor to the large difference between the two frequency bands could be the heavy foilage present in the area at the time of the measurements (June). The presence of foilage could also be a cause of the overall very rapidly increasing path loss with distance: 48 dB/dec at 900 MHz and 55 dB/dec at 1800 MHz. We must emphisize that this is a conclusion based on measurements in one area only, and we feel that measurements in more locations are needed.

In the investigated area the difference in coverage at 900 MHz and 1800 MHz is substantial. If we consider an output power of +40 dBm and demand -80 dBm average power at the mobile, then the -120 dB level in Fig. 5 predicts a coverage radius of 3250 m at 900 MHz but only 1550 m at 1800 MHz. However, if the 1800 MHz channels are intended for general capaicity improvement only, this difference may be be of small importance. In this case traffic within 1550 m may be moved to 1800 Mhz channels and the 900 MHz channels are left with the traffic at larger range.

Considering possible sources of error in this study, it is still safe to conclude that the coverage at 1800 MHz is less than at 900 MHz. For sub-urban areas, we therefore propose to maximize the antenna gain at 1800 MHz, i.e. to use the whole antenna aperture in both bands. We have presented such a dual polarized dual band antenna for the GSM-900 and DCS-1800 frequency bands. It is a base station sector antenna and the horizontal beamwidths at 915 MHz and 1785 MHz are 71.5° and 69° respectively. The port-to-port isolation is greater than 26 dB in both bands.

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