Reconfigurable Pico-cell Antenna Array for Indoor Coverage in GSM 900 Band

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Abstract. *This paper proposes a simple antenna array based on three stacked shorted patches aimed to be used as GSM (900 MHz) indoor base station antenna. Three same linearly polarized stacked patches are set in three orthogonal planes in space forming pyramid-like structure. The antenna array can be used for nearly omnidirectional coverage as well as for covering three 120° sectors. The proposed array also offers the possibility of polarization diversity.*

Keywords

Antenna size reduction, small antenna, shorted stacked patch, indoor coverage, sector coverage.

1. Introduction

Mobile communications are nowadays an important part of telecommunications, as well as everyday life. They are used both for military and civil purposes (e.g. cellular phones, computers, navigation devices). The antennas are necessary part of all such devices, since they are found on both sides of every wireless link. Therefore there is a challenge in the antenna design to meet some often contradictory demands. For instance, from engineers' point of view, the antennas should provide adequate signal coverage and/or reception in various environments. On the other hand, from designers' and users' point of view, they should be fitted in the environment properly, even better if they blend with it and seem invisible to general public. Microstrip antennas are nowadays very popular antenna type since they offer advantages of thin profile, light weight, low cost, conformability to a shaped surface and compatibility with integrated circuitry [1, 2].

Furthermore, the sizes of mobile devices have been dramatically reduced in last ten years, which lead to the need for reducing also the size of the antenna itself. Many techniques for antenna miniaturization have been proposed [3]. These techniques are however always a compromise among volume, bandwidth and efficiency and are mainly based on introducing shorting walls and modifications in the patch [2, 3].

The purpose of this paper is to present a design of a simple antenna array which could be used for transmitting and receiving in GSM 900 band in various indoor environments (office, hall, shopping mall…). Such array needs to provide suitable signal coverage, i.e. its radiation pattern should provide the EM field of approximately the same strength in every point of considered indoor space, meaning that such antenna needs to have omnidirectional radiation pattern in space. As mentioned above, such array also needs to be integrated in buildings and made esthetically acceptable to general public.

As a basic antenna for the array, quarter wavelength shorted stacked patch on the air substrate has been chosen. This antenna offers both size reduction as well as satisfactory impedance bandwidth without significant decrease in radiation efficiency [4, 5]. Furthermore, it can be easily manufactured and it is mechanically robust. With suitable radome it can be made esthetically acceptable.

The proposed array design can be efficiently used in the applications where simultaneous radiation pattern and polarization reconfigurability are a matter of concern.

2. Antenna Design

The commercial software CST Microwave Studio [6] was used to design and optimize the quarter wavelength shorted stacked patch (Fig. 1), as well as to compute the performance of the whole array. The integration of the patches in the array required some modifications in the patch design in order to improve the performance of the system.

The single antenna consists of a coaxial-probe-fed main (lower) patch, a parasitic (upper) patch, and a common shorting wall connecting both patches to the ground plane (Fig. 1). Both patches are placed in the air environment. In the final design, the side walls were added to reduce mutual coupling between antennas. In Tab. 1 the dimensions of a single patch are summarized. These values were obtained through optimization process which required suitable impedance matching (SWR < 2) in the bandwidth for GSM band (880 ÷ 960 MHz). As expected, the resonant length is a bit less than $\lambda/4$ at the central frequency (920 MHz), due to the fringing effects [7]. The calculated current distribution on the stacked patch confirms the excitation of the TM_{01} mode. An example of the calculated current distribution on the considered antenna at frequency 920 MHz is shown in Fig. 2.

	Length	Width	Height
Driven patch	7.9 cm	4 cm	1 cm
Parasitic patch	6.5 cm	7.2 cm	2 cm
Ground plane size	16 cm x 12 cm		
Shorting wall height	4 cm		
Additional side walls' height	2 cm		
Feed point location	1.9 cm from the shorting wall along the axis of symmetry		

Tab. 1. Single patch dimensions.

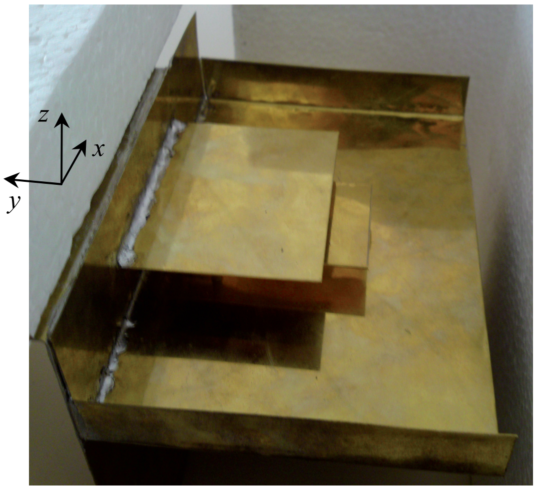

Fig. 1. Single shorted stacked patch used in the antenna array. (The coordinate system used in radiation pattern measurement is defined on the left.)

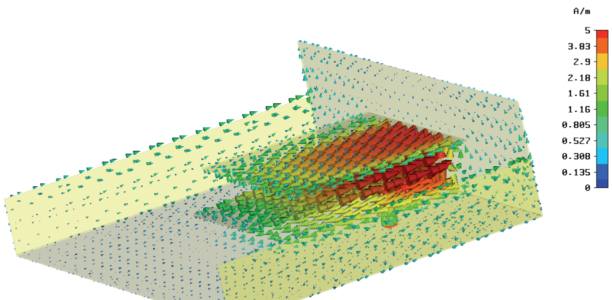

Fig. 2. Calculated current distribution on the stacked patch from Fig. 1 at 920 MHz.

Three identical shorted patches, designed as described before, have been set in three orthogonal planes forming a pyramid-like array. Due to modifications in the patch configuration (extension of shorting wall and additional sidewalls), the mutual coupling parameter (S_{21}) in the whole frequency band of interest has been reduced bellow –20 dB. The calculated array radiation pattern showed satisfactory hemispherical coverage (Fig. 3). A dip in the radiation pattern in the direction of the volume diagonal of the cube formed by the three antennas is not a real disadvantage, because the mobile terminals passing bellow such base station antenna are at the smallest distance from it exactly in the direction of this dip.

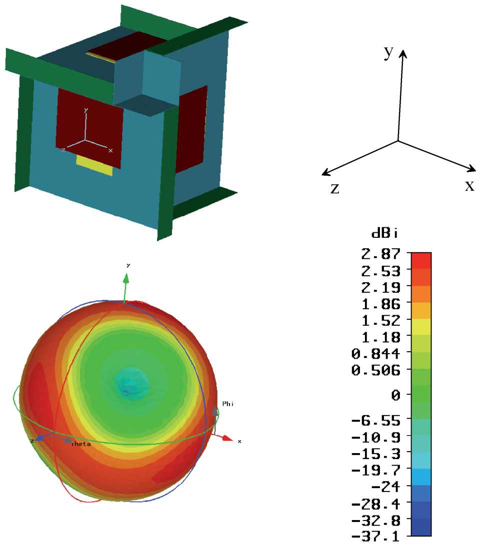

Fig. 3. Array structure and the calculated 3D radiation pattern (in-phase excitation) (f = 920 MHz).

3. Antenna Measurements

When the optimization process was completed, the three single antenna prototypes were manufactured. They have been used as building elements for the array.

The R&S ZVA 40 vector network analyzer has been used for measurement of the input impedance of the array elements as well as for measurement of radiation patterns of the single radiating element and of the whole array.

3.1 Single Antenna

The measured reflection coefficients (S_{11}) of all the three antennas are given in Fig. 4. All the antennas have good impedance matching in the GSM band, which agrees well with the simulation results. Also the measured results show that the proposed antenna design is robust and that it has good manufacturing repeatability.

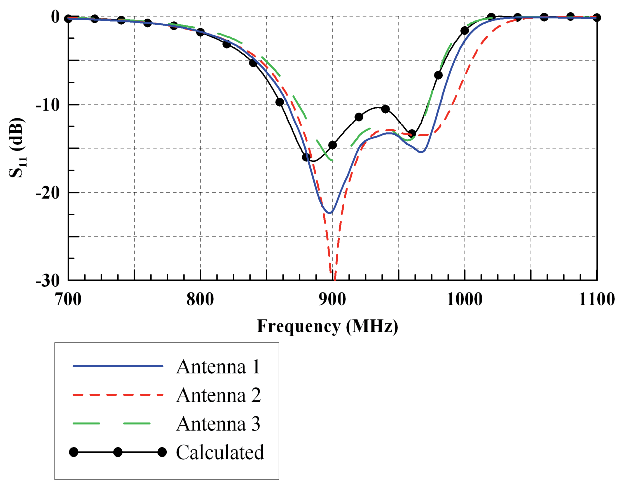

Fig. 4. Calculated and measured reflection coefficients vs. frequency.

The comparison between calculated and measured gain patterns of a single antenna (shown in Fig. 1) are given in Figs 5 ÷ 7, for the frequencies of 880, 920 and 960 MHz, respectively. The gain patterns were measured in *E*-plane (*y-z* plane in Fig. 1) and *H*-plane (*x-z* plane in Fig. 1), both for co-polarization and cross-polarization. Good agreement between calculated and measured results is obtained.

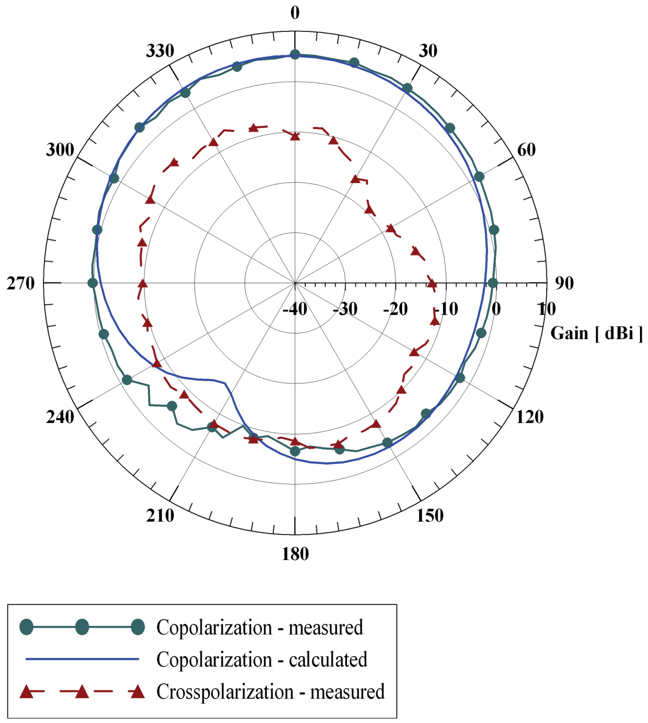

Fig. 5a. Gain pattern of a single antenna at 880 MHz (*E*-plane).

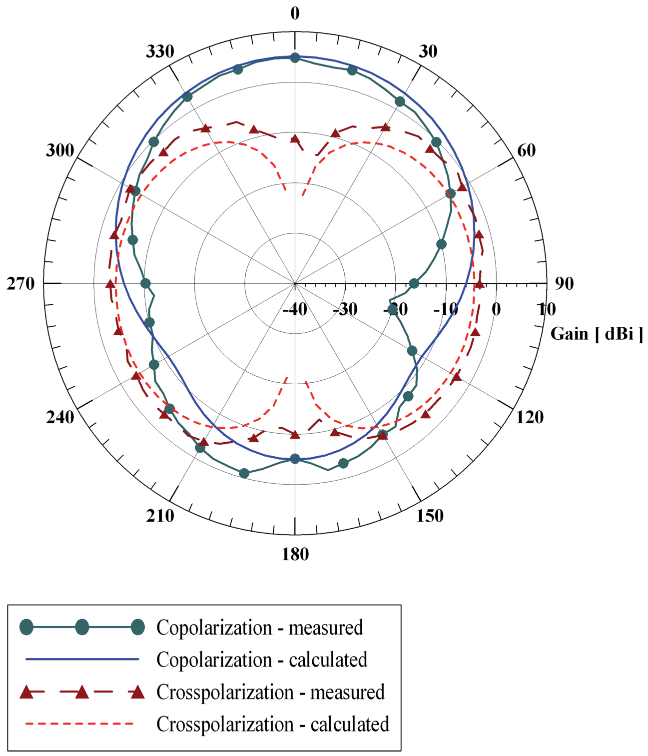

Fig. 5b. Gain pattern of a single antenna at 880 MHz (*H*-plane).

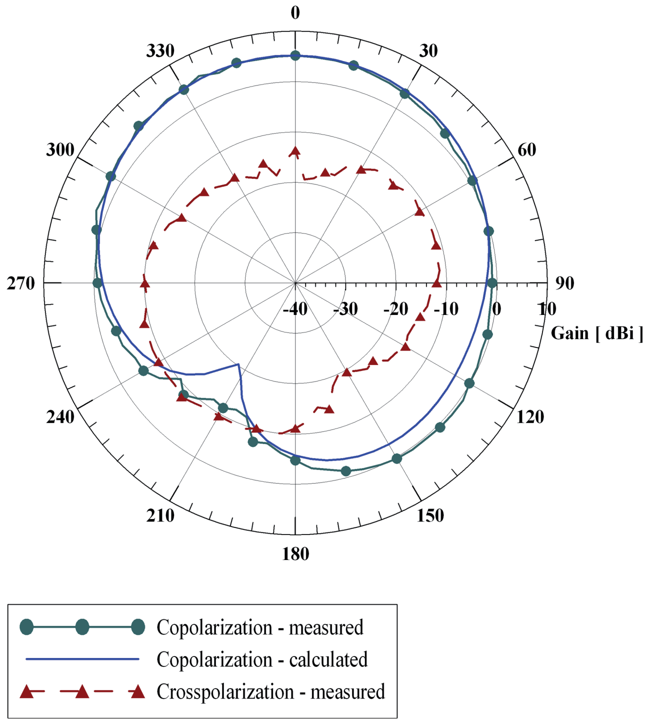

Fig. 6a. Gain pattern of a single antenna at 920 MHz (*E*-plane).

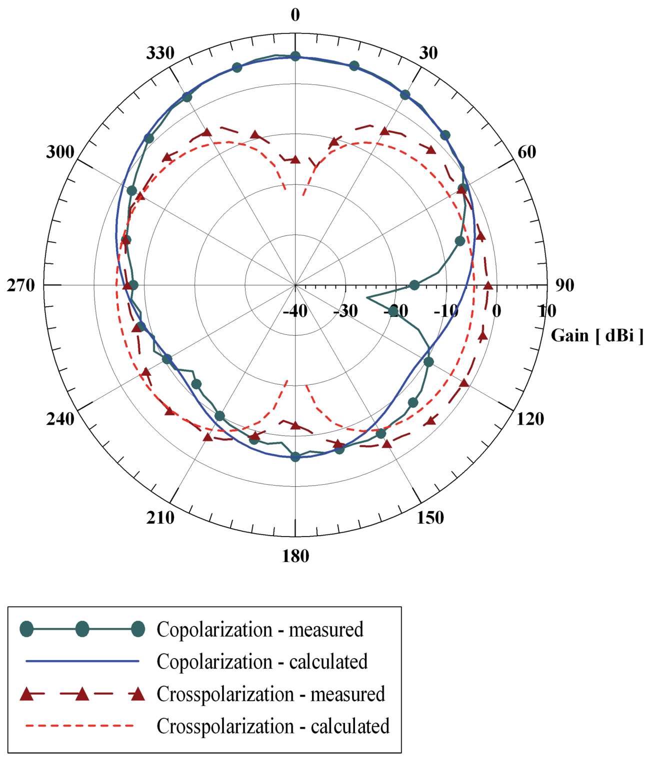

Fig. 6b. Gain pattern of a single antenna at 920 MHz (*H*-plane).

The maximal gain of about 5 dBi was measured in the broadside direction. The measured cross-polarization levels in *E*-plane are about 15 ÷ 20 dB below the co-polarization levels in the broadside direction. As expected the calculated *E*-plane cross-polarization levels were nearly zero and therefore they are omitted in Figs 5 ÷ 7.

In *H*-plane for some directions the cross-polarization level was found to be significantly higher than the co-polarization one. Such high cross-polarization levels were observed also by other authors for similar shorted patch antennas [8].

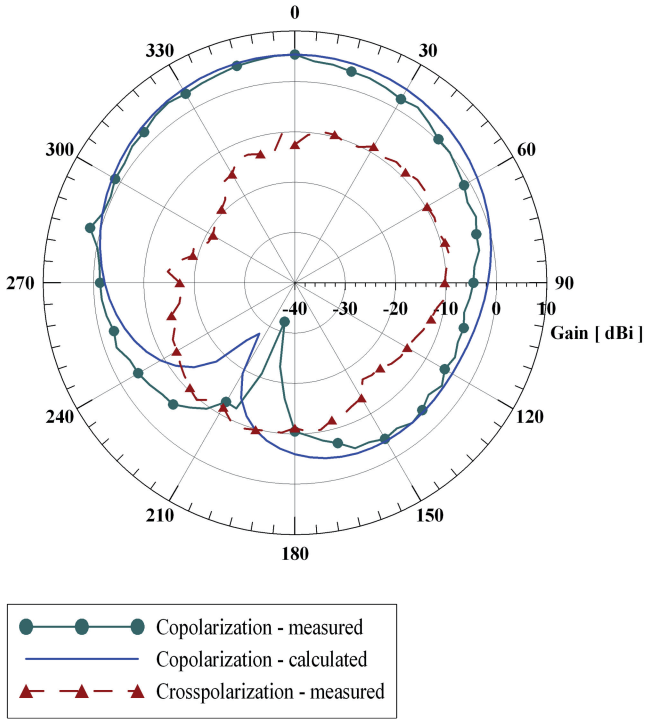

Fig. 7a. Gain pattern of a single antenna at 960 MHz (*E*-plane).

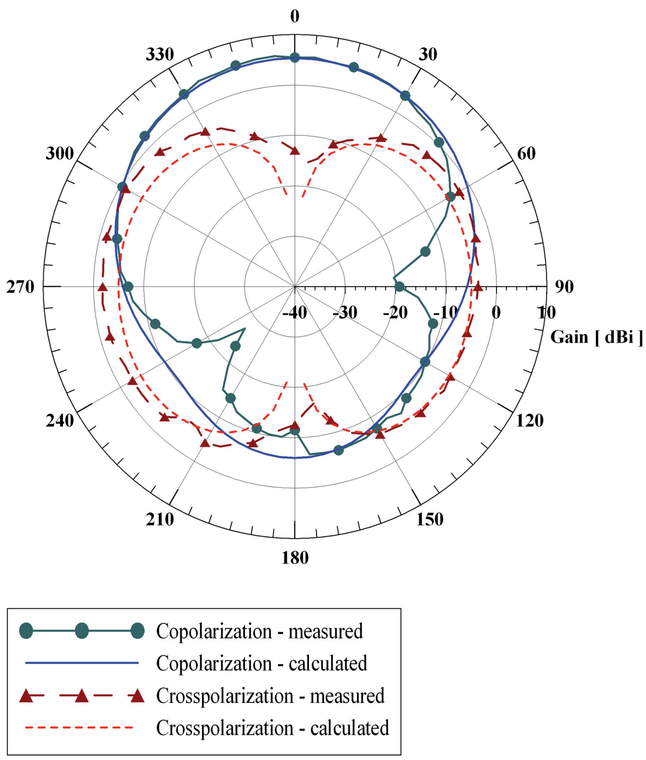

Fig. 7b. Gain pattern of a single antenna at 960 MHz (*H*-plane).

3.2 Antenna Array

Three single antennas were integrated in an array, as shown in Fig. 8. The proposed array is intended to be put e.g. on the ceiling of the room and to provide appropriate signal coverage for users in all parts of the room.

Three excitation schemes of the array were investigated. In the first excitation scheme all three antennas have been excited in-phase which should provide nearly hemispherical coverage (as shown in Fig. 3).

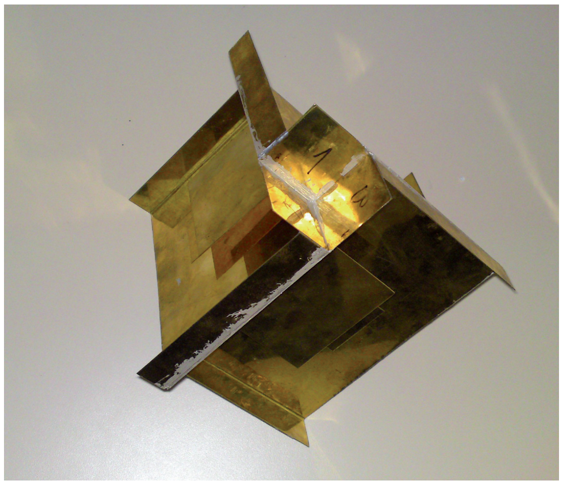

Fig. 8. Antenna array prototype.

The radiation patterns of the array for the in-phase excitation of all three antennas were measured at the characteristic frequencies of GSM band (880 MHz, 920 MHz and 960 MHz). A calibrated $\lambda/2$ dipole antenna was used as a measurement antenna. The schematic of the measurement setup is given in Fig. 9. The measurements were performed in azimuthal (φ) plane for three elevation angles (θ = 0º, 30º and 60º), while the φ = 0º direction was chosen along one edge of the pyramid-like antenna structure. Measurements were performed for both vertical and horizontal polarizations.

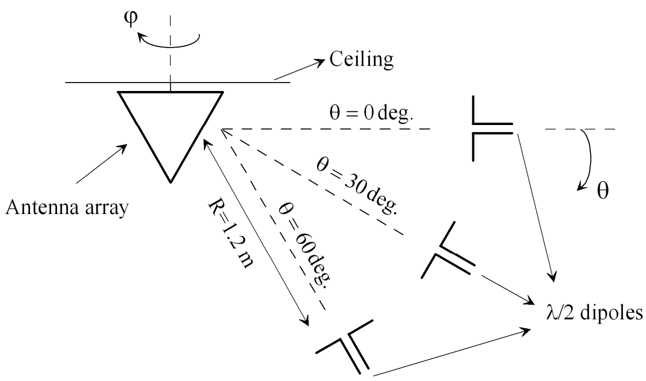

Fig. 9. Schematic of the measurement setup.

The measured radiation patterns at the central frequency (920 MHz) are given in Figs 10 ÷ 12, for elevation angles 0º, 30º and 60º, respectively. Results for other frequencies in the GSM band show almost the same behavior.

All measurement results are normalized to the measured values obtained for vertical polarization in $\varphi = 0^{\circ}$ and $\theta = 0^{\circ}$ direction. The measured patterns show satisfactory nearly-hemispherical coverage.

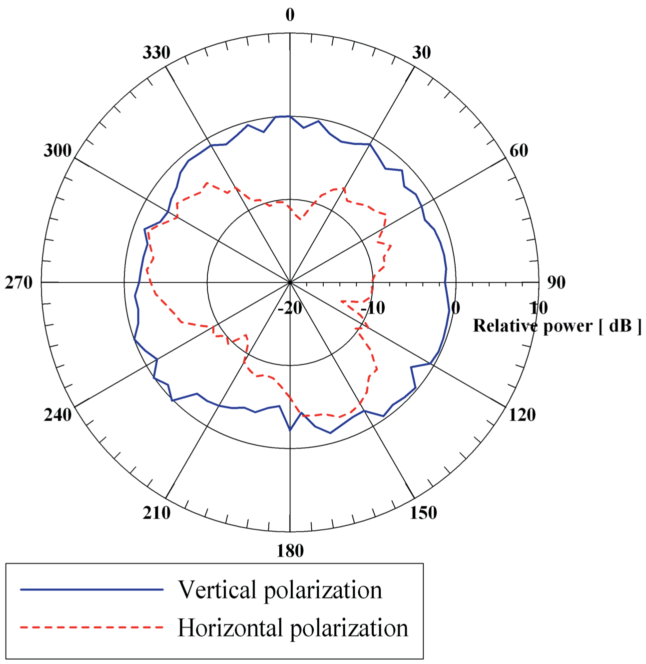

Fig. 10. Measured radiation pattern of the arrayat 920 MHz for $\theta = 0^{\circ}$ (all elements excited in-phase).

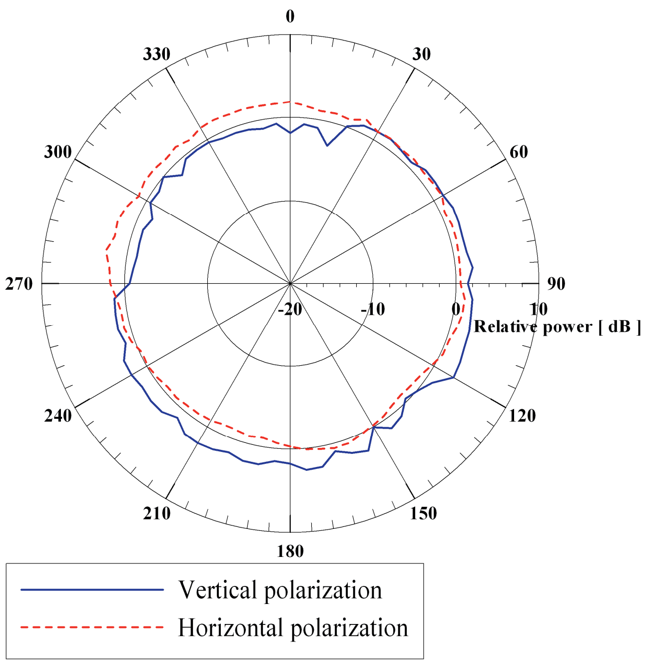

Fig. 11. Measured radiation pattern of the array at 920 MHz for $\theta = 30^{\circ}$ (all elements excited in-phase).

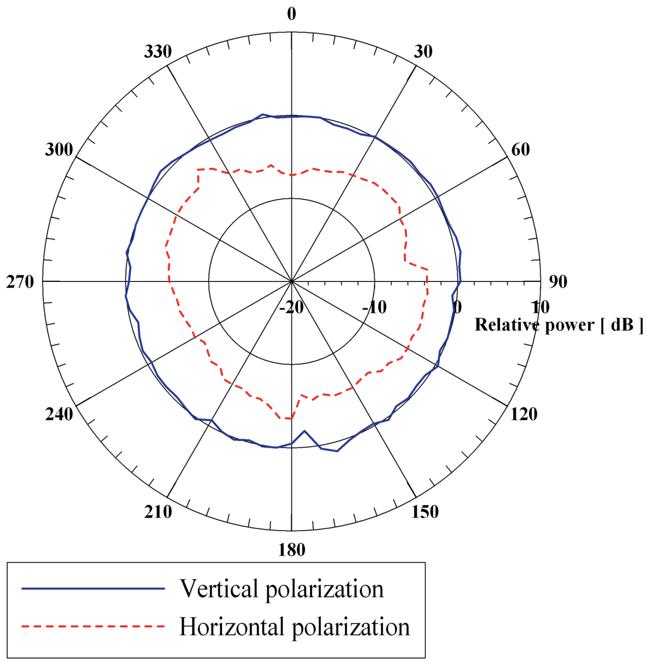

Fig. 12. Measured radiation pattern of the array at 920 MHz for $\theta = 60^{\circ}$ (all elements excited in-phase).

The second excitation scheme which was investigated is independent excitation for each antenna. In this case this array would not operate as an array but rather as three antennas covering three sectors in space. The array can be electronically reconfigured between these two excitation schemes by switching the antenna feeding networks. Such reconfigurability allows the base station to adapt its capacity and coverage depending on the number of mobile terminals within its area. When the number of users is small, the omnidirectional coverage can be used. On the other hand, when the number of users increases, the number of sectors can also be increased offering increased capacity.

For the case of separate antenna excitation, the radiation patterns were also measured for three frequencies in the GSM band (880 MHz, 920 MHz and 960 MHz) and three elevation angles (Fig. 9). One antenna in the array was excited while the inputs of the other two antennas were terminated with matched loads. As the measured mutual coupling between the antennas in the array is bellow –20 dB, the measured radiation pattern of one antenna should be applicable also to the other two in the case of independent antenna excitation. The radiation patterns were measured for horizontal and vertical polarization, but also for two slanted polarizations at +45° and +135°. (Here the direction of the horizontal polarization is considered as 0° while the direction of the vertical polarization is considered as 90°.) The $\varphi = 0^{\circ}$ direction (azimuth reference) was again chosen along one edge of the pyramid-like antenna structure. The results are presented in Figs 13 ÷ 15.

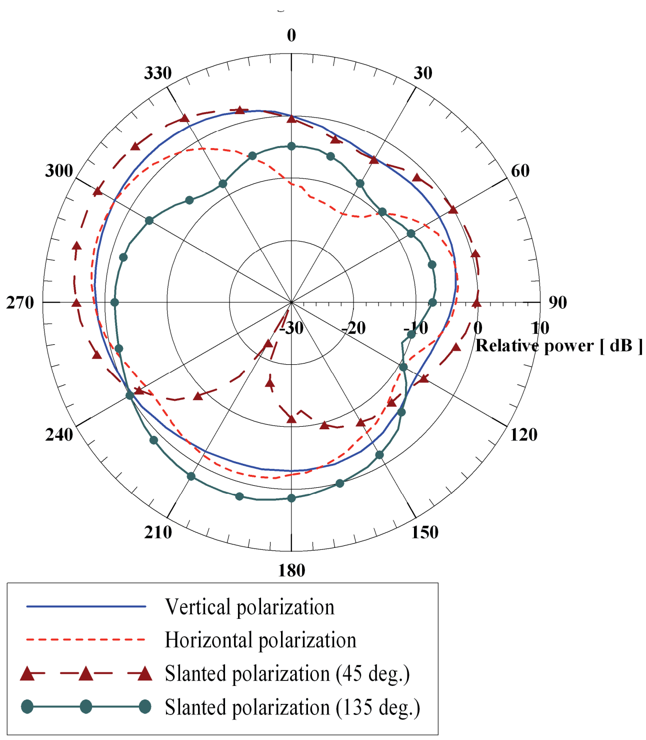

Fig. 13. Measured radiation pattern of the array at 920 MHz for elevation $\theta = 0°$ (only one antenna excited).

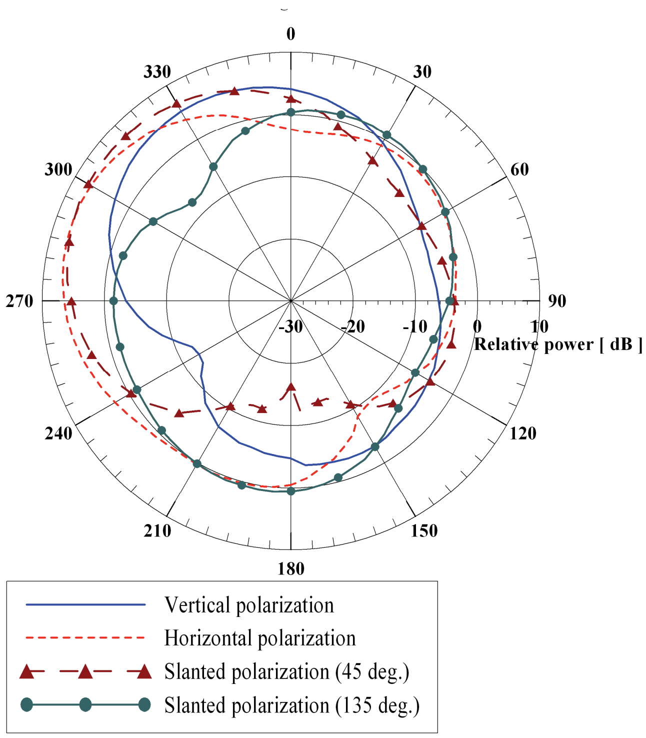

Fig. 14. Measured radiation pattern of the array at 920 MHz for elevation $\theta = 30°$ (only one antenna excited).

As it can be seen from the measured radiation patterns in Figs 13 ÷ 15, the single antenna mounted on the pyramid-like structure has a broad beam, but the beamwidth and beam maximum direction change with frequency and with the measured polarization. From the measured beamwidth it follows that three antennas with such radiation patterns and with maxima pointing to three directions 120° apart, can provide adequate signal strength in the surrounding space. Although the change of the beam direction with the change of the polarization could be considered as a disadvantage, it can be turned to an advantage which allows usage of polarization diversity to improve the quality of the communication link.

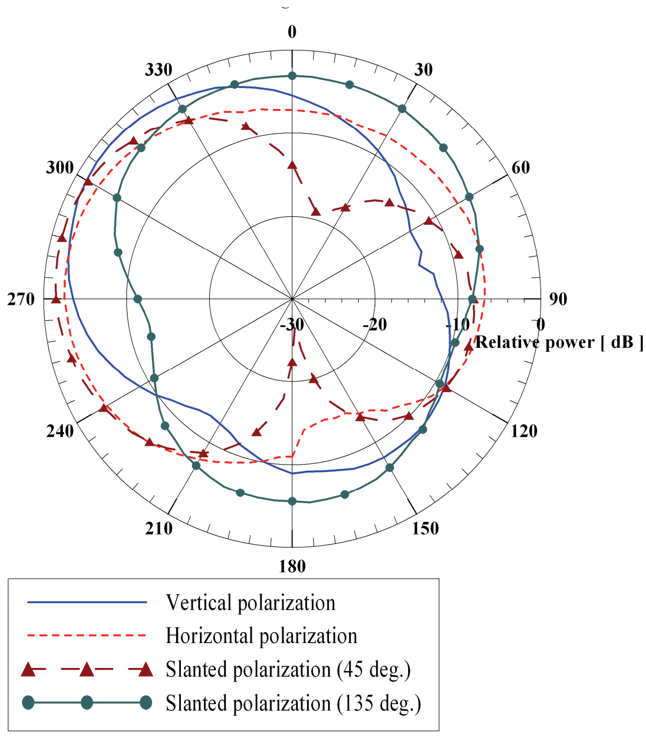

Fig. 15. Measured radiation pattern of the array at 920 MHz for elevation $\theta = 60°$ (only one antenna excited).

The third excitation scheme should produce two sectors, one of 240° and the other of 120°. Two antennas should be excited in-phase, while the third one should have independent excitation. This excitation scheme has also been experimentally investigated. However, as the two antennas which should operate in-phase have different polarizations, the resulting radiation pattern does not show the required beamwidth for covering a 240° sector. In contrast to this, it should be pointed out that the first excitation scheme (all three antennas excited in phase) does not suffer from similar problems because the array (Fig. 8) for the first excitation scheme is rotationally symmetrical.

Finally, it can be concluded that only the first two excitation schemes are of practical importance for the proposed array.

4. Conclusion

The paper presents the design of stacked shorted patches which are used for integration in a pyramid-like array. This antenna array is intended to be used as an antenna for indoor base stations of the GSM 900 mobile communication system. The array is relatively compact and it provides enough space for the feeding networks within the pyramid formed by the patch ground planes. The measured radiation patterns of the array with all antennas excited in phase show satisfactory nearly-hemispherical coverage.

The proposed array can be also used as a set of three independently excited antennas, where each antenna is covering one approximately 120° wide sector. Radiation patterns for this case have also been measured showing satisfactory coverage. As the single antennas placed in a pyramid-like structure present different polarizations, there is also a possibility to use polarization diversity.

The proposed array can be switched from hemispherical coverage to three-sector configuration by switching the feeding network. Future work will include the design of an appropriate electronically switched feeding network. By switching the array from hemispherical coverage to three-sector configuration the base station can be dynamically reconfigured to accommodate e.g. increased number of users.

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Branimir IVŠIĆ was born in Zagreb, Croatia, in 1982. He received his M.Sc. degree from the Faculty of Engineering and Computing, University of Zagreb in 2006. Since 2007 he is a research assistant at the Department of Wireless Communications of the Faculty of Electrical Engineering and Computing, University of Zagreb. His main research interests are electromagnetic scattering, small antennas and electromagnetic sensors.

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Juraj BARTOLIĆ was born in Zagreb, Croatia, in 1948. He received the Dipl. Ing., M.S., and Ph.D. degrees in Electrical Engineering from the University of Zagreb in 1971, 1975, and 1982, respectively. From 1972 to 1974 he worked for the Radio Industry of Zagreb in R&D of microwave radio. In 1974, he joined the Institute for High Frequency Techniques, Faculty of Electrical Engineering at the University of Zagreb, were he was a research assistant, assistant professor, and associate professor. Currently, he is a professor in the Department of Wireless Communications, Faculty of Electrical Engineering and Computing, University of Zagreb. He served as Head of the Department from 2000 to 2004. Since 1998 he is a member of the Croatian Academy of Engineering. He is the co-author of the book Mixing, Mixers, and Frequency Synthesizers, and the author and co-author of more then 150 technical papers in journals and conferences. His research interests include electromagnetics, antennas and propagation, wireless circuit design, microwave engineering, and electromagnetic compatibility (EMC). He is a Senior Member of IEEE.