Radiation and Bandwidth Characteristics of Two Planar Multistrip Antennas for Mobile Communication Systems

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Abstract — In this paper, the measured radiation and bandwidth characteristics of two slightly different short-circuited microstrip patch antennas are reported. The bandwidth of the studied antennas has been enhanced by dividing one wider patch into separate narrower patches which are tuned to different resonant frequencies. One of the patches is fed and the others are parasitically coupled. The results indicate that without increasing the volume occupied by the antenna its impedance bandwidth can be more than doubled with this method. In addition, the study shows that the use of parasitic elements may cause the polarization of the antenna to become frequency dependent.

I. INTRODUCTION

Short-circuited microstrip patch antennas can be used as directive internal handset antennas in various communication systems. As directive internal antennas, they are expected to provide advantages over the omnidirectional external helix and whip antennas in terms of increased efficiency (when the handset is near the user's head), decreased radiation towards the user [1], and increased mechanical reliability [2]. More general advantages include low profile, low cost, constructional simplicity, light weight, structural robustness, integrability with other circuits, and the possibility to make the antenna conformal [3]. The main disadvantage is the inherently narrow impedance bandwidth. There are, however, several known techniques which can be used to improve the impedance bandwidth [4]. Of all the reported techniques perhaps the most challenging one is the introduction of additional resonators into the structure of the antenna while keeping its overall volume small. One well known example of such an antenna is the radiation-coupled dual-L antenna (RCDLA) [2,5,6], in which a coplanar short-circuited parasitic patch is coupled to a similar driven patch by proximity effects to obtain a doubly tuned resonance and a wide bandwidth. The same basic idea has also been used in the back-mounted microstrip double patch antenna (BMMDPA) [7] and in the enhanced-bandwidth version of the dual-L antenna [8]. The bandwidth characteristics and the interaction between a human and the dual-L type antennas have already been studied and reported by the authors of [2, 5–8]. However, only a limited amount of material is available on the radiation and, in particular, on the polarization characteristics of these antennas. The purpose of this paper is to provide more information on these important characteristics. Several prototype antennas in which the number of patches varied from one to three were constructed and measured in the investigation. The measured results for two of the studied antennas are presented and discussed in this paper.

II. SHORT-CIRCUITED DUAL-PATCH MICROSTRIP ANTENNA

The first studied antenna consisted of two relatively narrow patches which were separated by a narrow gap and short-circuited to a small ground plane with thin copper foils (Fig. 1). The short-circuited patches were tuned to different resonant frequencies by adjusting their lengths. A probe feed was connected to the longer one of the patches, while the shorter one was parasitically coupled. The dielectric material between the patches and the ground plane was RT/duroid 5870 with $\varepsilon_r = 2.33$, and $\tan\delta = 0.0012$. The thickness of the substrate, which together with its relative permittivity has the most significant effect on the impedance bandwidth of this antenna, was 4 mm.

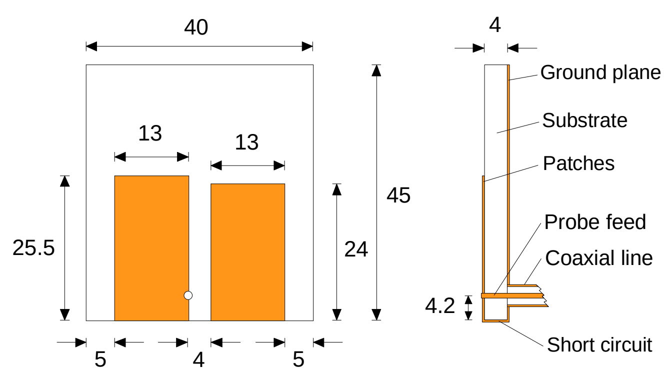

Fig. 1. Short-circuited dual-patch microstrip antenna. All dimensions are in millimeters.

The described antenna is here referred to as the short-circuited dual-patch microstrip antenna. It is similar to the antennas presented in [5–8]. The main difference between this one and the antennas studied in [5–8] is that in this version the separation between the patches is constant all the way from the short-circuit to the radiating edges. It was attempted to make this antenna simpler in order to see whether it is possible to obtain a dual-resonant antenna without extensions near the short-circuited edge or without the tapering of the slot near the open edge.

The measured impedance bandwidth ($L_{retn} \geq 10$ dB) for the short-circuited dual-patch antenna was 6.4 % at the center frequency of 1.83 GHz (Fig. 2). This is 2.2 times the bandwidth of 2.9 % measured for a single-patch reference antenna with the patch size 24.5 mm × 30 mm (*length* × *width*). The size of the ground plane and the substrate parameters were equal for the reference antenna and the studied antennas. Therefore, it may be concluded that by dividing the radiating patch of a short-circuited microstrip antenna into two narrower stagger-tuned patches its impedance bandwidth can be more than doubled without increasing the volume occupied by the structure.

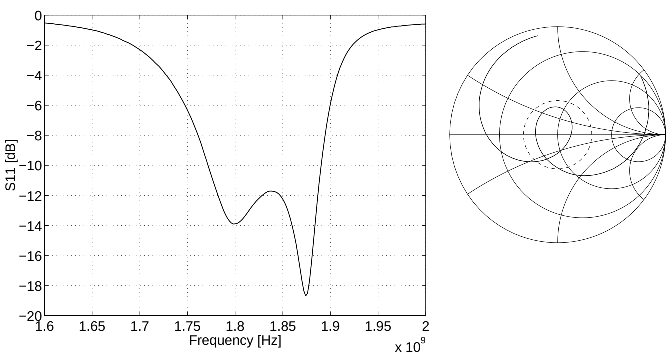

Fig. 2. Measured reflection coefficient for short-circuited dual-patch microstrip antenna. Dashed line on the Smith chart represents the reflection coefficient which corresponds to the return loss $L_{retn} = 10$ dB.

The first studied antenna consists of two patches which have different lengths and resonant frequencies. At a chosen frequency the fields of the patches are likely to have different amplitudes and phases, which means that there is an amplitude and phase difference between the patches. These differences will change as the frequency changes. The radiation patterns of the dual-patch antenna were measured at several frequencies to find out how the changing amplitude and phase differences would affect them.

In the proximity of the lower resonance, the radiation pattern of the short-circuited dual-patch antenna was very similar to that measured for the single-patch reference antenna. This leads to the conclusion that only one of the patches, the longer driven one with the lower resonant frequency, was radiating. As shown in Fig. 3, the level of crosspolarization increased considerably as the frequency was increased and the parasitic patch began to resonate. In the proximity of the lower resonance, the half-power beamwidths of the antenna were approximately 120° in the E-plane (x-z) and 100° in the H-plane (x-y). It was observed that as the frequency increased from 1.78 to 1.88 GHz the direction of the main lobe in H-plane turned from 0° to –25°.

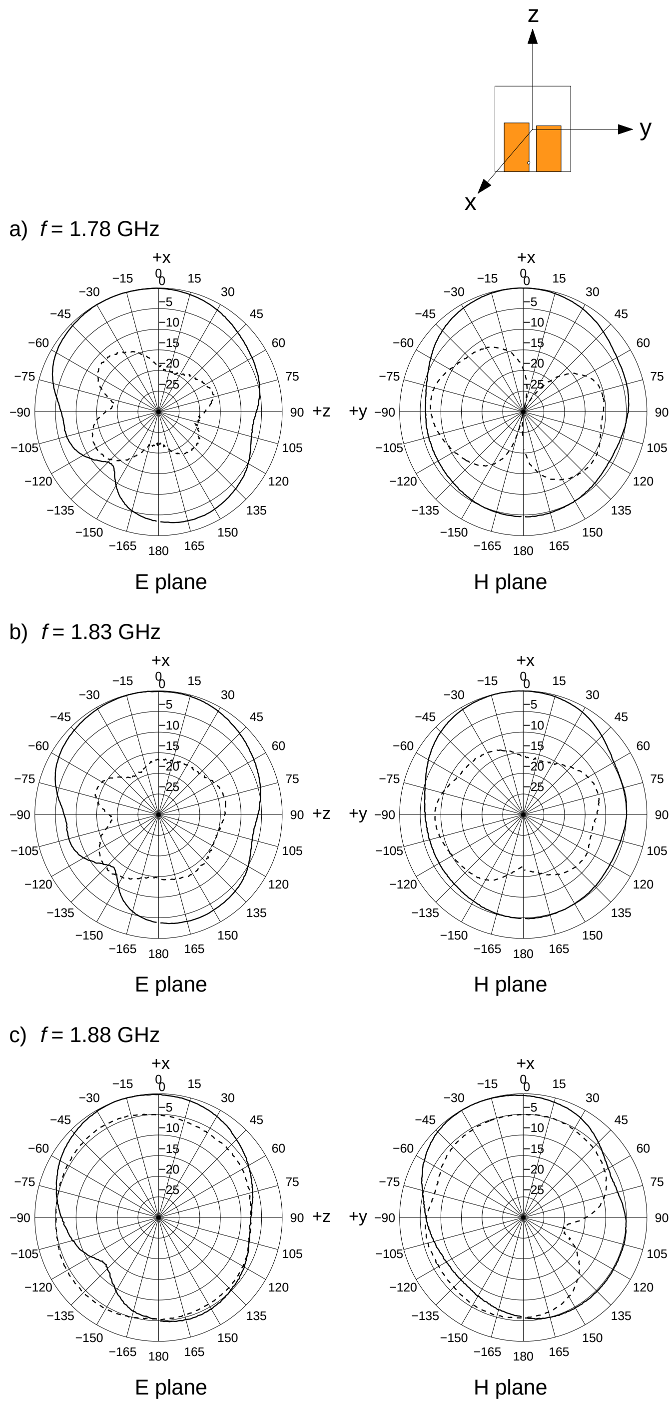

Fig. 3. E- and H-plane normalized radiation patterns measured at 1.78, 1.83, and 1.88 GHz for short-circuited dual-patch microstrip antenna.

The gain of the dual-patch antenna was measured in the broadside direction (direction of x-axis in Fig. 3). The measurement was based on the Friis transmission formula. At 1.8 GHz the measured gain was 3.8 ± 1.1 dBi. Fig. 4 presents the measured transmission coefficients between the dual-patch antenna and a standard gain horn antenna with orthogonal polarizations. The highest level of the solid curve corresponds to the measured gain at 1.8 GHz. The figure shows how the received power level drops with the desired polarization before the upper limit of the impedance bandwidth (1.89 GHz) because of polarization mismatch.

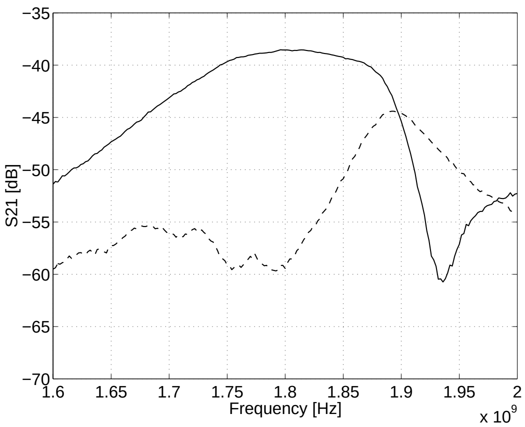

Fig. 4. Measured transmission coefficient in broadside direction between short-circuited dual-patch antenna and standard gain horn antenna. Solid line represents copolar and dashed line crosspolar transmission.

The polarization characteristics of the dual-patch antenna were studied in the broadside direction (direction of x-axis in Fig. 3) with a network analyzer by measuring the transmission coefficient between the studied antenna and a standard gain horn antenna with two orthogonal polarizations (vertical and horizontal). This provided the amplitudes and phases of the two corresponding electric field components as functions of frequency and enabled the determination of the polarization ellipses. The crosspolarization level of the standard gain horn, which was used in the measurement, was less than –40 dB in the measurement direction.

The polarization ellipses in Fig. 5 have been drawn to represent waves which are radiated by the studied antenna. The direction of propagation is from the picture towards the reader. The directions in Fig. 5 correspond to the directions in Figs. 1 and 3. According to Fig. 5, the polarization of the dual-patch antenna changed considerably as a function of frequency. Near the lower resonant frequency, which is the resonant frequency of the driven patch, the antenna radiated mainly vertical polarization. As the frequency increased the polarization began to tilt. At the upper limit of the impedance bandwidth (1.89 GHz) the polarization had tilted 39° counterclockwise from the vertical position.

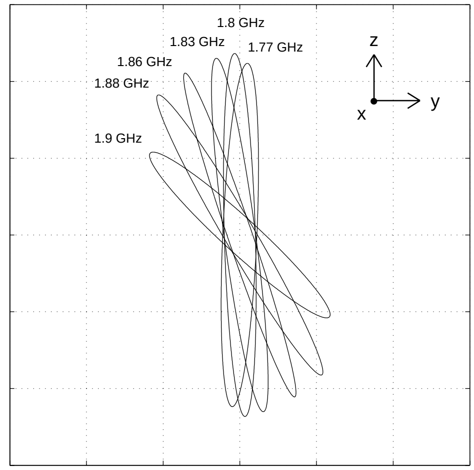

Fig. 5. Polarization ellipses at several frequencies for short-circuited dual-patch microstrip antenna.

III. SHORT-CIRCUITED TRIPLE-PATCH MICROSTRIP ANTENNA

The short-circuited triple-patch microstrip antenna was constructed using the same substrate material and feeding method which were used with the dual-patch antenna. The number of parasitic patches was increased to two in order to see its effect on the radiation characteristics and also to see if the bandwidth could be further increased. In this antenna the feed was connected to the widest patch.

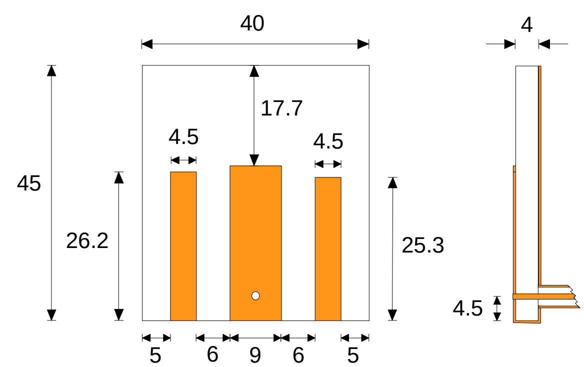

Fig. 6. Short-circuited triple-patch microstrip antenna. All dimensions are in millimeters.

The short-circuited triple-patch antenna could not be matched as well as the dual-patch antenna due to strong coupling between the driven and the parasitic patches. On the Smith chart of Fig. 7, this can be seen as two relatively large loops of which only the smaller one would fit inside the circle denoting the reflection coefficient which corresponds to $L_{retn} \geq 10$ dB. However, by relaxing the matching requirement to the level $L_{retn} \geq 8$ dB, a continuous impedance bandwidth of 8.4 % with the center frequency of 1.78 GHz, can be found.

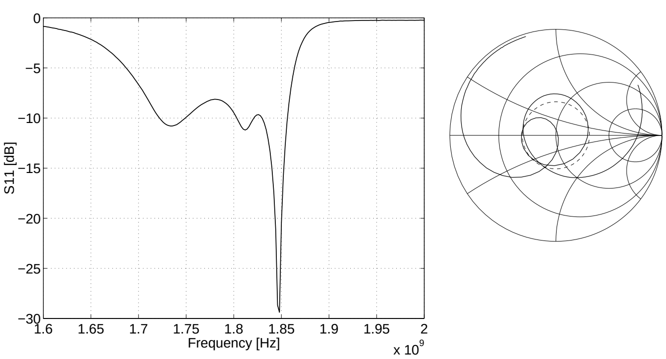

Fig. 7. Measured reflection coefficient for short-circuited triple-patch microstrip antenna.

At certain frequencies the radiation patterns measured for the triple-patch antenna were quite similar to the radiation patterns of the dual-patch antenna. In the proximity of the lowest resonance the radiation patterns were almost identical to the radiation patterns of the single-patch reference antenna and the dual-patch antenna close to its lower resonance, see Figs. 3 a) and 9 a). As the parasitics began to resonate the crosspolarization level increased and exceeded the level of the copolar pattern around 1.82 GHz. As shown in Fig. 7, this is almost exactly between the resonant frequencies of the parasitic patches. At 1.85 GHz the radiation pattern of the triple-patch antenna was again almost identical to that of the dual-patch antenna at 1.88 GHz, see Figs. 3 c) and 9 c). This suggests that at 1.85 GHz only one parasitic patch, the shorter one with the higher resonant frequency, was interacting with the driven patch. The measured gain in the broadside direction for the triple-patch antenna was 3.7 ± 1.1 dBi at 1750 MHz. By comparing Figs. 7 and 8, it can be seen how the received copolar power level changes inside the impedance bandwidth of the antenna due to changes in its polarization.

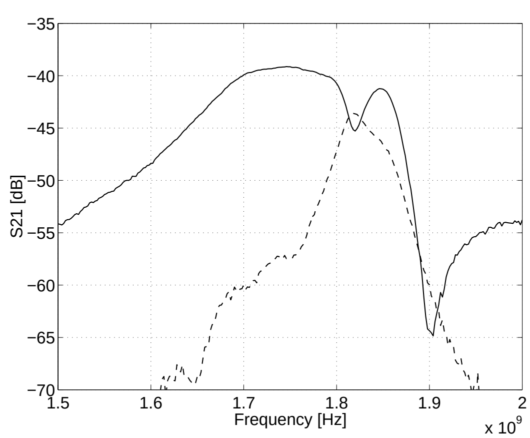

Fig. 8. Measured transmission coefficient in broadside direction between short-circuited triple-patch antenna and standard gain horn antenna. Solid line represents copolar and dashed line crosspolar transmission.

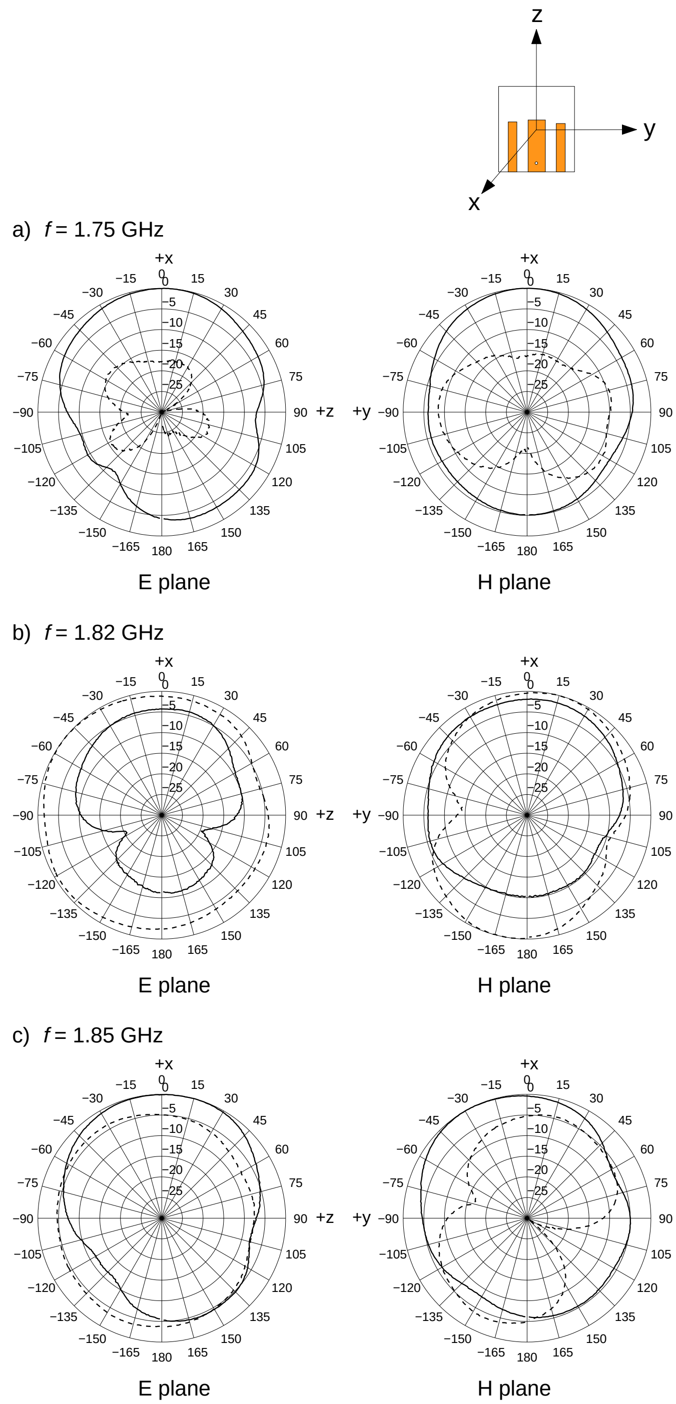

Fig. 9. E- and H-plane normalized radiation patterns measured at 1.75, 1.82, and 1.85 GHz for short-circuited triple-patch microstrip antenna.

At the lowest resonant frequency, which is the resonant frequency of the driven patch, the polarization of the triple-patch antenna was almost vertical and linear (Fig. 10). This suggests that there was very little interaction between the driven and parasitic patches. As the longer parasitic patch (on the left side of the driven patch in Fig. 6) began to resonate, the polarization of the antenna tilted to the right, away from the resonant parasitic patch. At 1.82 GHz the polarization ellipse was almost circular. Because the frequency 1.82 GHz was between the resonant frequencies of the parasitic patches, it may be assumed that both parasitics were interacting with the driven patch. As the frequency was increased, the effect of the longer parasitic decreased and because the shorter parasitic began to resonate its effect increased. At resonant frequency of the shorter parasitic, the polarization ellipse was almost a mirror image of the polarization ellipse at the resonant frequency of the longer parasitic patch. It seems that at the resonant frequencies of the parasitic patches the polarization ellipses tilt approximately 30° from the vertical position in the direction which is away from the direction of the resonant parasitic patch in question. This holds also for the dual-patch antenna, see Fig. 5. The result is logical in the sense that in both antennas the lengths of the parasitic patches compared to the driven patch are almost equal. Therefore, the amplitude and phase differences between the fields of the parasitics and the driven patch are likely to be close to each other in all three cases.

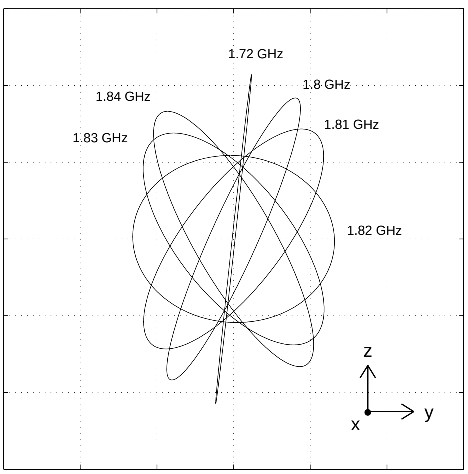

Fig. 10. Polarization ellipses at several frequencies for short-circuited triple-patch microstrip antenna.

In a propagation environment where the vertically polarized field is much stronger than the horizontally polarized field the described changes in polarization may have a significant effect on a mobile communication system. Different frequency channels may have different polarizations which causes significant variations in the effective gain. In speaking position the typical tilting of a mobile phone is about 60 degrees. If we had antenna with quite linear but 60 degrees tilted polarization, then the actual polarization of the received/transmitted field would depend on which side of the head the user would hold the telephone. On one side the field would be vertical and on the other side horizontal.

IV. CONCLUSIONS

The radiation and bandwidth characteristics of two small planar multistrip antennas were studied experimentally. The results indicate that the impedance bandwidth of a small short-circuited microstrip patch antenna can be more than doubled by dividing its patch into two narrower patches which are tuned to different resonant frequencies. It may be possible to improve the impedance bandwidth even more by dividing one patch into three narrow strips. This may, however, lead to strong coupling between the driven and parasitic patches and thus problems in the matching of the antenna. The use of parasitic patches in the studied configuration has a considerable effect on the radiation pattern of the antenna. The crosspolarization level increases considerably as the parasitic patches begin to resonate. The polarization becomes elliptical and tilted. The tilt angle and the axial ratio of the polarization ellipse may change rapidly as functions of frequency.

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