Air-Filled Stacked-Patch Antenna

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Abstract

This paper presents a new design of a broadband dual-polarized stacked-patch antenna having no dielectric substrates or foam materials. The patches, the groundplane with two excitation slots, and the feed lines of the antenna are cut out of metal sheet. Only some small dielectric spacers, metal posts, and bolts are used to fasten the antenna parts together. The antenna has a relative bandwidth of 24 % with the return losses better than -14 dB at both ports. The port decoupling is better than 32 dB in the entire frequency band. The designed radiator can be used as a single element of a multi-band base station antenna covering GSM1800/1900, DECT, and UMTS frequency bands.

1 Introduction

Each microstrip patch antenna consists at least of one feed line and one radiating element. To increase the bandwidth of a microstrip antenna, additional parasitic radiators, placed in the same or in different layers, are used [1]. In the case of different layers, the radiators (patches) as well as feed lines (in aperture-coupled antennas) are etched on different dielectric substrates with a relative permittivity larger than one. Fig. 1 shows a typical structure of the aperture-coupled stacked-patch antenna. Some additional dielectric layers are usually needed to support the etched patches and a quarter-wavelength reflector. Thus, up to 6 and more dielectric layers are commonly used in a microstrip antenna. This makes such antennas expensive and therefore unsuitable for mass production, for example, as a base station antenna for cellular communication systems.

In [2], a new design of a base station antenna was proposed with the idea to use small dielectric posts to support two patches, cut out of metal sheet, in an aperture-coupled stacked-patch antenna with two offset slots. In that way, the dielectric layers 1 – 4 (Fig. 1) were replaced by dielectric posts. Using this approach, a broadband dual-polarized stacked-patch antenna with a –10 dB bandwidth of 28.7 % was developed and introduced in [3]. In the present paper we investigate the possibility to remove all the dielectric layers 1 – 6 (Fig. 1) and discuss the advantages of this antenna concept.

2 Antenna Design

The proposed antenna (Fig. 2) consists of two stacked patches, a groundplane, and a reflector, all having a square shape and lying in parallel planes with equal orientation of the edges.

Fig. 1 Exploded view of a common microstrip patch antenna.

Fig. 2 Exploded view of the proposed antenna.
The patches are supported by two short metal posts in the center of each patch and are fixed to the ground-plane with a metal bolt going through the small holes in the patches and the posts. The same fastening principle is used to attach the reflector to the ground-plane. In this case, quarter-wavelength posts are placed in the corners and, if necessary, in the center between the reflector and the groundplane (these posts are not shown in Fig. 2). The patches, the ground-plane, and the reflector are cut out of metal sheet with a thickness of 0.5 mm. The posts have a diameter of 5 mm. Fig. 3 shows a photograph of an implemented antenna with metal posts.

![Fig. 3](image)

Fig. 3 Photograph of the antenna (top view).

The feed lines are cut out of metal sheet with a thickness of 0.3 mm and have a distance of 0.57 mm to the groundplane. Some dielectric spacers are used to maintain the feed lines in fixed positions (Fig. 4).

![Fig. 4](image)

Fig. 4 Photograph of the antenna (bottom view).

Two orthogonal slots are cut out in the groundplane (Fig. 4) to enable the patches to be electromagnetically coupled to the feed lines. The off-set arrangement of the slots is necessary because of the metal posts supporting the patches. The second important function of the metal posts is the DC-grounding of the patches and the reflector, which is essential to ensure the lightning protection and avoid high voltages between antenna parts.

Basically, it does not matter which kind of metal is utilized for the antenna. We used both brass and aluminum for different antenna parts, and no differences were observed between them. However, the use of equal materials is preferable because of different electromechanical properties and temperature expansion coefficients.

3 Feed Lines

The characteristic impedance of the feed lines (metal strips) depends on the strip width, the distance from the strip to the groundplane, and the thickness of the strip. There is an infinite set of these parameters, which results in a 50 Ω feed line. We investigated two feed lines with a width of 2.5 mm and 5 mm, and a distance to the groundplane of 0.57 mm and 1.1 mm, respectively. Both strips have a thickness of 0.3 mm. The theoretical and experimental investigations show that both feed lines can achieve approximately the same results as a microstrip line, etched on a dielectric substrate, in the discussed antenna design. So, the same bandwidth and other radiation characteristics can be attained using any of these three feed lines.

4 S-Parameters

The initial design of the antenna was made using the Ansoft Ensemble simulation tool based on the method of moments. A stacked-patch antenna structure with resonant slots was chosen to achieve a large bandwidth, and an off-set arrangement of the slots is used to produce two orthogonal polarizations. Such an antenna produces three coupled resonances which have to be equally distributed in the band of operation. The antenna was optimized with the aim to achieve the best possible impedance matching and port decoupling in the frequency range from 1.71 GHz to 2.17 GHz. Fig. 5 shows the simulated S-parameters of the antenna after the initial optimization process.

![Fig. 5](image)

Fig. 5 Simulated S-parameters of the antenna.
Since a real antenna never has absolutely the same S-parameters as a simulation model, the initially designed antenna was further optimized experimentally. For this purpose, a number of antenna prototypes with different geometrical dimensions was made and analyzed. **Fig. 6** shows the measured S-parameters of the experimentally optimized antenna.

The measured reflection coefficients (S11 and S22) of both ports are better than -14 dB, and the port decoupling (S12=S21) is better than 32 dB in the frequency range from 1.71 GHz to 2.17 GHz. These results satisfy the requirements of a multi-band base station antenna, covering GSM1800/1900, DECT, and UMTS frequency bands. The large bandwidth is achieved by optimizing the positions of the three coupled resonances (two patches and one slot), which build two loops on the Smith chart (**Fig. 7**).

A very interesting fact is that the simulated and measured decoupling between the antenna ports is better than 32 dB, which is very unusual for an aperture-coupled patch-antenna with off-set slots. Normally, a port decoupling of 15-20 dB is observed in such type of dual-polarized antennas [1]-[5]. The reason of the high port decoupling is the metal posts supporting the patches. **Fig. 8** shows the simulated S-parameters of the antenna with simulation results shown in **Fig. 5**, but without the metal posts in the center of the patches. This is just a theoretical model. In praxis, the patches can be supported by small dielectric posts or foam layers.

**Fig. 7** Smith chart of the measured input impedances of the antenna at both ports.

**Fig. 8** Simulated S-parameters of the antenna without metal posts.

Figs. 5 and 8 illustrate the influence of metal posts on the S-parameters of the antenna. Additional theoretical and experimental investigations show that the input reflection coefficients (S11 and S22) of the antenna without metal posts can be optimized again and reach the same values as in **Fig. 5**. However, the port decoupling always remains on the level of 15-20 dB, even if the positions of the excitation slots and the angle between them are optimized. The further interesting fact is that the introduced air-filled antenna achieves the same performance as an antenna with etched feed lines. **Fig. 9** shows the measured S-parameters of an antenna with the patches used for the air-filled antenna but having feed lines etched on a dielectric substrate.

**Fig. 9** Measured S-parameters of the antenna with etched feed lines.

As it can be seen in Figs. 6 and 9, both antennas have comparable impedance matching and port decoupling.
5 Far Field Patterns

Fig. 10 shows the measured H-plane radiation patterns of the antenna with metal posts and a quarter-wavelength reflector. The reflector is as large as the groundplane and is supported by four metal posts in the corners of the reflector. Only one port was excited during the measurements while the other port was terminated with a 50 Ω load.

The far field patterns of the second port are similar to those of the first one. The measured beam width is about 70 degrees for both ports. The back radiation is lower than -18 dB. The measured cross-polarization level is below -16 dB. One of the possible reasons why the measured cross-polarization is much higher than the port decoupling is the cross-polarization of the used reference antenna which is about -20 dB in this frequency range.

6 Gain

Fig. 11 shows the measured and simulated gain of the antenna. Only one port was excited during the measurements while the other port was terminated with a 50 Ω load, and only the co-polar field was measured.

The average measured gain of the antenna is about 9 dBi, which is a typical value for stacked patch antennas. The measurements show that the designed air-filled antenna has the same radiation properties as conventional dual-polarized patch antennas.

7 Conclusion

This paper presents a new design of a broadband dual-polarized stacked-patch antenna with a -14 dB bandwidth of 24 % and a port decoupling of 32 dB. The antenna covers GSM1800/1900, DECT, and UMTS frequency bands and can be used as a single element of a high-gain base station antenna. The air-filled antenna does not utilize any dielectric substrates or foam materials, and does not need any etching processes to be manufactured. The main parts of the antenna are cut out of metal sheet and assembled using some small metal posts, dielectric spacers, and bolts. Both patches and the reflector are directly DC-grounded via the metal posts with a diameter of 5 mm. The antenna exhibits very good mechanical properties and ensures a longer service life compared to the conventional patch antennas, suffering from high material costs, moisture absorption, and temperature dependency.

The presented low-cost antenna design can be easily scaled for operation in other frequency ranges.

8 Literature