Multireflector Antennas – Cascaded Structures with Frequency Selective Surfaces

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Abstract. *The problem of increasing the gain of directional multiband antennas is solved in the paper. A single-fed multiband (wideband) planar dipole is combined with cascaded (sandwiched) reflectors made of frequency selective surfaces. Each of those reflectors is placed in a quarter-wavelength distance from the dipole at the frequency of operation.*

The impedance matching is particularly achieved by active element properties, and impedance symmetrization. Further transformation is made by a planar circuit, placed on the active element plane. The antenna gain is set by the reflector elements amount (reflector plane dimensions). The antenna structure enables its setting into arrays with in-phase feeding.

Keywords

Multiband antennas, directional antennas, frequency selective surfaces, cascaded structures.

1. Introduction

The current development in wireless communication technologies requires the design of antennas that can be used in several frequency bands. Typically, a dual-band antenna is required to operate at GSM 900 MHz and at 1 800 MHz in Europe. Many applications use the ISM 2.4 GHz band. With the increasing demands on performance, many services move now to 5.7 GHz band with the requirement on synchronous services in the original band.

At the present, slightly directional antennas designed for mobile handsets or similar terminals belong to the most often realizations of antennas. The planar inverted-F antennas (PIFAs) [1] and the U-shaped slot antennas [2] are the most frequently used types.

Providing an adequate feeding and a sufficient impedance matching is the fundamental problem when increasing the directivity of multiband antennas. Conventional passive directors and reflectors are hardly applicable due to the requirement of a multiband behavior.

In the paper, the methodology of a compact directional multiband antenna design is therefore proposed, discussed and verified on examples.

2. Active Element

The planar dipole antenna has been found as the most appropriate active element in the proposed design. The dimensions accuracy and the reproducibility of wire antennas are difficult to be reached. Moreover, their use at microwave frequencies is not efficient. On the other hand, the use of planar patch antennas is problematic due to the continuous ground plane excluding the possibility of using reflectors. But, the planar printed technology is easy to manufacture and reproduce, exhibits low production costs, and can be modified in order to enable completing the antenna by the reflector. Therefore, the planar technology was chosen to build the antenna.

As an active element, a dipole is used. It usually operates in the quarter-wave resonance ($2\,l = \lambda/2$) with the input impedance in 70÷75 Ω and the directivity 2÷2.5 dBi. Some applications take advantages of the half-wave resonance operation with the input impedance much higher (usually in hundreds of Ohms) and a slightly higher directivity 2.5÷3.5 dBi. In common structures, the resonance frequency ratio (f_2/f_1) is generally close to 1.85, and therefore, the dual-band operation is not commonly used. In higher resonances, the radiation pattern is rather problematic – shows many side lobes, and the main lobe is oriented out of the direction of interest (low operational directivity).

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In order to enforce the dipole to exhibit a multi-band behavior, the fractal theory has been introduced to the antenna design. A plenty of the fractal dipole antennas have been published in literature (the Koch dipole, the Sierpinski dipole, etc.) to be used in a multiband operation. As an essential problem of fractal dipoles, we can consider their high resonant resistance ratio (R_2/R_1): the dipole resistance in quarter-wave resonances is between 10÷50 Ω while the input impedance in half-wave resonances is in thousands of Ohms.

Instead of fractal dipoles, we have therefore used basic modifications of printed dipole structures (Fig. 1): a thick dipole (a), an arm-extending dipole (b), and an arm-tapering dipole (c). Those dipoles were found to be the most suitable for a multiband operation with a low resonant resistance ratio. Results of the detailed analysis are summarized in [3].

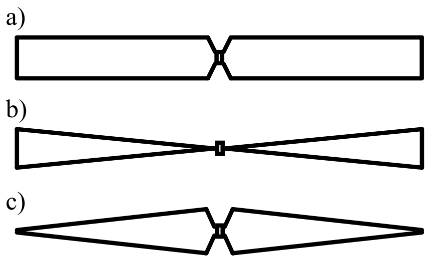

Fig. 1. Basic modifications of a planar printed dipole: a) thick one, b) arm-extending one, c) arm-tapering one.

Performing the numerical analysis of the dipoles depicted in Fig. 1, following conclusions can be formulated:

- The thick dipole can operate in GSM 900/1800, ISM 2.4/5.3 or ISM 2.4/5.7, with the input impedance 30÷40 Ω in the first band and 120÷300 Ω in the second one. In the triple-band NMT/GSM or GSM/Bluetooth, the dipole operates with the input resistance 21÷32 Ω, 130÷150 Ω and 45÷155 Ω in resonances.
- The arm-extending dipole can operate in GSM 900/1800, ISM 2.4/5.3 and ISM 2.4/5.7 with the input impedance 40÷55 Ω in the first band and 400÷800 Ω in the second one. These values are suitable for creating dipole arrays completed by feeding, which exploits the transforming properties of transmission lines. That way, the input impedance can be decreased in the second band, and can be kept the same in the first band. A triple-band operation in NMT/GSM or GSM/Bluetooth shows the input impedances 50÷60 Ω, 300 to 400 Ω and 150÷160 Ω in respective resonances.
- The arm-tapering dipole can operate in GSM 900/1800 and ISM 2.4/5.3 or 2.4/5.7 in the first resonance and the third one showing the input impedance close to 50 Ω both. This is naturally efficient for single-standing element. The triple-band NMT/GSM or GSM/Bluetooth operation is possible with 12÷25 Ω, 110÷120 Ω and 25÷50 Ω.

In order to illustrate the design procedure, a 2.4 GHz / 5.7 GHz arm-tapering dipole antenna has been designed using the results of a wideband analysis [3]. Zeland IE3D (frequency domain method of moments) was used to analyze the antenna. For simplicity, a symmetrical feeding is considered. Computed parameters (reflection coefficient and radiation patterns in E plane and H plane) are depicted in Fig. 2.

A tapered microstrip balun [4] is applied in order to reach the impedance symmetrization. No impedance transformation is used.

3. Reflectors

Planar reflectors are usually used for narrow-band applications. In some cases, those reflectors can operate up to 1:2 frequency band (an analog terrestrial TV broadcasting, e.g.). Cascading of reflectors is excluded even when using a wire-grid reflector.

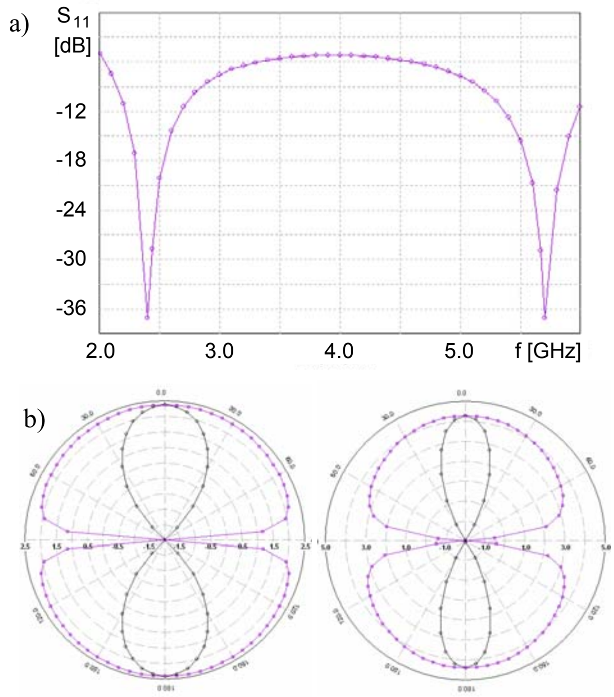

Fig. 2. The arm-tapering printed dipole antenna designed for the operation at frequencies 2.44 GHz and 5.67 GHz: a) frequency response of the reflection coefficient at the antenna input; b) directivity pattern at the frequency 2.44 GHz (left) and 5.67 GHz (right).

On the other hand, cascaded reflector structures can be built from frequency selective surfaces (FSS). In the role of a reflector, FSS were used in Cassegrain systems [5] for the first time. Frequency response of the FSS reflectivity typically exhibits several maxima and minima. When FSS is used as a reflector, the first maximum of the reflectivity should be exploited. In besides the reflectivity decreases; and the antenna looks like a dipole in free space. The operating frequency depends directly on the shape and the dimensions of the frequency selective motif.

Frequency selective surfaces are typically periodic arrays of identical elements, which exhibit electric conductivity (patches, crosses, etc.) or magnetic conductivity (slots, etc.). A frequency selective behavior of FSS is achieved by constructive and destructive interferences of waves produced by currents induced to conducting elements. When used as a reflector, rectangular elements or circular strip loop ones are efficient for using as a FSS motif. Here, the operation band is sufficiently wide, and sidebands with low reflection are close to it. Also, the accidental and parasitic bands exhibiting a high reflection are in a sufficient distance from the operation band.

When designing the first reflector (the highest operation frequency), an auxiliary symmetrically fed dipole is placed in a half-wavelength distance from the active element, and the reflector plane is placed in between. FSS motive is optimized in order to reach the lowest transmission s_{21} (the highest reflectivity) and sufficient reflection coefficient s_{11}. After finishing this FSS optimization, the auxiliary dipole is removed and the structure (both the active dipole and the reflector) are optimized again for sufficient s_{11}. This moment, the antenna acts as the dipole in free space outside the operation band, and as a dipole completed by a planar reflector inside the operation band.

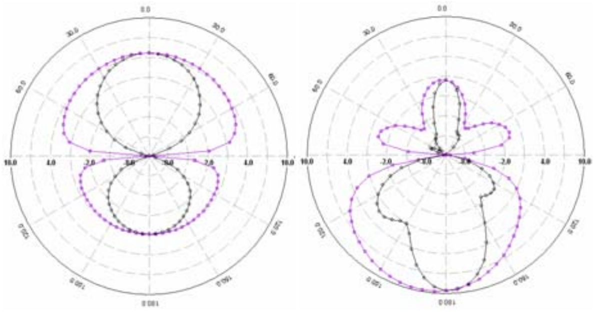

Fig. 3. Directivity pattern of the arm-tapering printed dipole antenna completed by a single FSS reflector at the frequency 2.44 GHz (left) and 5.67 GHz (right).

For the design, Zeland IE3D was used again. Radiation patterns at 2.4 GHz and 5.7 GHz (both E plane and H plane) are depicted in Fig. 3. The array of 2×3 rectangular strip loops was used as the reflecting structure in the higher band.

In the next step of the multi-reflector antenna design, the second reflector plane (and potentially the other ones) has to be set. In the presented design, two rectangular loops were used as the second reflector. The design procedure is identical as in the case of the first reflector (the auxiliary dipole is used to reach the desired s_{21} of the reflector, and subsequently, the reflector is optimized to exhibit the desired s_{11}). The resulting structure and achieved parameters (current distributions, impedance matching and radiation patterns in E plane and H plane) are shown in Fig. 4.

The developed antenna system exhibits a good impedance matching (VSWR better than 1.2 inside the whole operation bands). The directivity of the antenna is 7.2 dBi in the 2.4 GHz band and 10.1 dBi in the 5.7 GHz band. The physical dimensions of the antenna developed on the substrate Arlon 25N ($h = 0.762$ mm, $\varepsilon_r = 3.38$, tan $\delta = 0.0025$) are 44 × 86 mm.

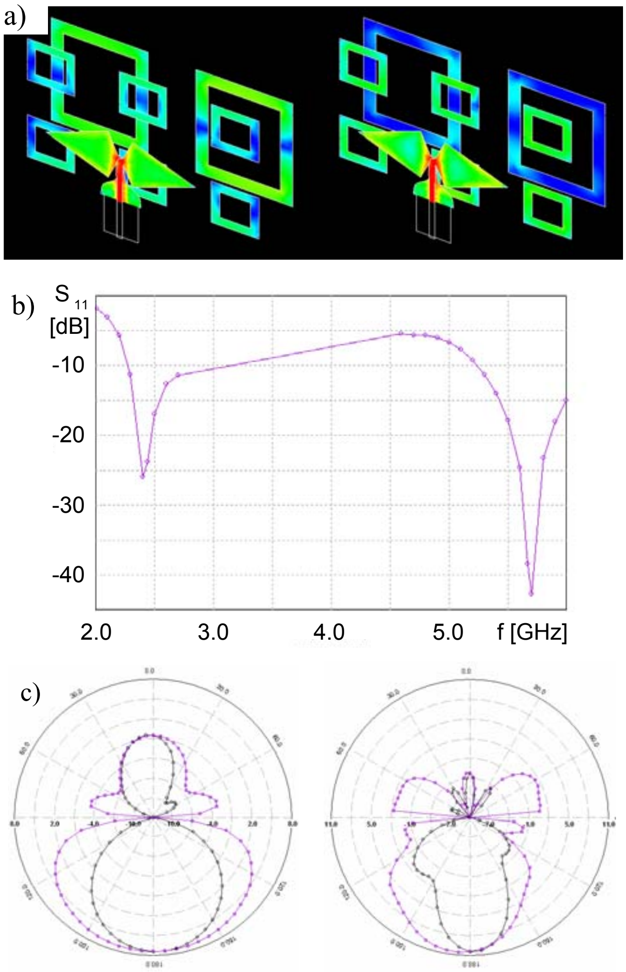

Fig. 4. The arm-tapering printed dipole antenna completed by two FSS reflectors: a) current distribution on the antenna at the frequency 2.44 GHz (left) and 5.67 GHz (right), b) frequency response of the reflection coefficient at the antenna input; c) directivity pattern at the frequency 2.44 GHz (left) and 5.67 GHz (right).

The designed antenna was built and measured. Parameters of the prototype agree well with the Zeland IE3D model. The measured reflection coefficient s_{11} (Fig. 5) is better than -20 dB inside the whole operation bands. Radiation patterns are of the similar shape in both the bands. The gain (corresponding to the model) exceeds the value 7 dBi in 2.4 GHz band and the value 11 dBi in the higher band (measured using RSSI values in a real radio link in comparison to commercial antennas).

4. Conclusions

The paper presents methodology of a novel multiband directional antenna design. The antenna consists of fed elements operating in resonances and cascaded frequency selective reflectors (a sandwiched planar structure).

A suitable shape and dimensions of the active element are designed using results of the numerical analysis performed in Zeland IE3D. A proper impedance matching is achieved by a wideband tapered microstrip balun.

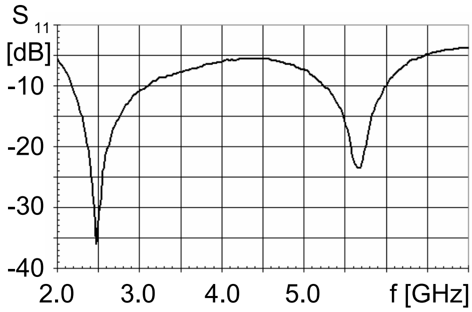

Fig. 5. Frequency response of the reflection coefficient of the built prototype of the arm-tapering printed dipole antenna completed by two FSS reflectors.

The antenna concept is based on cascading frequency selective surfaces in order to build a multiband planar reflector. The proper dimensions of rectangular loops (elements of FSS) are computed again in Zeland IE3D, using an auxiliary dipole.

The dual-band ISM 2.4/5.7 GHz antenna was realized in order to illustrate and verify the concept and design methodology. Following the described design procedure, the design can be repeated for different frequency bands, substrates and input impedances.

For the circular polarization, a circular strip loop motif can be used in combination with an appropriate active element. For further increasing the gain of the antenna, active elements can be grouped into an in-phase fed array. The expected gain for a quad array is then about 13 dBi in the lower band and 16 dBi in the upper band.

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References

[1] CIAIS, P., STARAJ, R, KOSSIAVAS, G, LUXEY, C. Design of an internal quad-band antenna for mobile phones. *IEEE Microwave and Wireless Components Letters*. 2004, vol. 14, no. 4, p. 148-150.

[2] PALMERO, E., RAIDA, Z., RUIZ, R. Quad-band U-slot antenna for mobile applications. *Radioengineering*. 2006, vol. 15, no. 2, p. 22-29.

[3] HERTL, I. On multiband properties of printed dipole antenna. In *Radioelektronika 2005 - conference proceedings*. Brno (Czech Republic), 2005, p. 121 – 124.

[4] ENGARGIOLAX, G. Tapered Microstrip Balun for ATA Feed Development. ATA Memo 35 rev 1.
(URL: http://astro.berkeley.edu/ral/ata/memos/memo35r1.pdf)

[5] WU T.-K., LEE S.-W. Multiband frequency selective surface with multiring patch elements. *IEEE Transactions on Antennas and Propagation*. 1994. vol. 42, no. 11, p. 1484 – 1490.

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Zdeněk NOVÁČEK (*1945) graduated at the Faculty of Electrical Engineering and Computer Science in 1969. At the present, he is an associate professor at the Dept. of Radio Electronics, Brno University of Technology. His research activities are oriented to the design of special purpose radiating systems, to near-field antenna measurements, and to temporal-spatial signal processing. He is author or co-author of more than 30 papers in journals and conference proceedings, and 10 textbooks.