Research Article

A Compact Wideband Dual-Polarized Antenna with Harmonic Suppression Using Nonuniform Defected Ground Structure

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A wideband dual-polarized coplanar waveguide (CPW) fed antenna integrating a wide stop-band filter is presented. The designed filter is based on a nonuniform defected ground structure (DGS) in order to obtain a wide stop-band and a compact size. This filter is used to reject harmonics and spurious radiation arising from the RF front end. The complete structure (antenna and filter) has been optimized to have a compact size of $0.6 \times 0.6 \lambda_0^2$ (λ_0 being the free-space wavelength at the lowest operating frequency). The realized antenna operates in the frequency range between 2.7 GHz and 5.9 GHz (bandwidth of about 74%). The isolation between feeding ports is more than 18 dB. The complete structure has a wide stop-band characteristic (103%) for harmonic rejection. The simulated numerical results have been confirmed with measurements.

1. Introduction

An active integrated antenna (AIA) introduces nonlinear devices directly into the radiating element. This concept was used to design antennas including high efficiency power amplifiers. However, these antennas exhibit high levels of harmonic radiation, which may degrade system performances [1]. In conventional systems, additional filters are used to remove these harmonics. However, these filters increase the size and the cost of radio frequency (RF) front ends and yield additional losses. Thus, it is interesting to perform this filtering function directly within the radiating element. This type of antenna allows the realization of compact RF front ends.

Several methods have been used to reject harmonics such as the insertion of slots and short-circuits [2] and the use of photonic band gap (PBG) [3, 4] or defected ground structure (DGS) [5, 6]. Finally, it should be noted that most studies have been carried out for narrowband structures.

A wideband antenna supporting a single field polarization has been recently presented in [7, 8]. Using these results, in this paper the design of a wideband dual-polarized

antenna, in which the matching circuit and the filter for harmonic rejection are integrated in the radiating element, is presented. The challenge was to reduce the isolation between the two input ports while maintaining a wide bandwidth and a compact size. Furthermore, a study about the radiation characteristics of the filter has been performed. The antenna provides wide bandwidth and dual polarization performance, in order to cover many communication standards and to transmit or receive any kind of field polarization (linear or circular). In [9], it has been shown that the diffraction processes arising from the presence of furniture may reduce the communication quality in indoor environments. Therefore, antennas that provide dual or circular polarization may be used to improve the service quality. On the other hand, the filter and the matching network are integrated parts of the radiating element. In this work, the radiating element, the filter for harmonic rejection, and the impedance matching network, which are traditionally separated circuits, are incorporated into a single unit.

The configuration of the proposed filter is shown in Section 2. Section 3 describes the design and the simulated and the measured results of the proposed antenna. The

FIGURE 1: DGS unit cells: (a) rectangular, (b) spiral, and (c) bowtie.

FIGURE 2: Geometry of the DGS filter.

discussion about the filter radiation is presented in Section 4. Finally, a conclusion of this work is given in Section 5.

2. DGS Filter Design

The filter is based on a defected ground structure (DGS) formed by three nonuniform unit cells. A DGS is a kind of electromagnetic band gap (EBG) structure. EBG structures forbid the propagation of electromagnetic waves in certain frequency bands known as band gaps. This property is used in many applications for the suppression of higher harmonics and undesirable frequency bands. DGS has the same advantages as the ones proposed by EBG structures in terms of size miniaturization, suppression of surface waves, and the ability to introduce distinctive stop-bands. The advantage of DGS over the EBG structures is that only one or few cells are needed instead of a periodic structure to produce the same performances. A DGS unit cell is a defect in the ground plane of a transmission line as that of a microstrip, coplanar, or any structure where a reference ground plane conductor exists. A variety of slot geometries have been proposed in the literature for filter design [10–12]. A parametric study has been carried out on three different compact geometries (rectangular, spiral, and bowtie) to select the most adapted unit useful to design the integrated filter (see Figure 1).

Table 1 summarizes the comparative study of the magnitude of the scattering parameter S_{21} ($|S_{21}|$) of each DGS unit cell. Simulations were performed with CST MWS (transient solver). The rejected bandwidth refers to a $|S_{21}|$ less than

TABLE 1: Rejected bandwidth for DGS unit cells.

Unit cells	Rejected band (GHz)	Bandwidth (%)
Rectangular	20.9–24.4	15.45
Spiral	7.2–8	10.5
Bowtie	9.6–12.55	26.6

–15 dB. After a comparison of the characteristics of several cells, bowtie unit cell was chosen because it has the widest rejected bandwidth and a compact size.

The designed filter is formed by means of three nonuniform cascaded unit cells, in order to obtain a wide rejected band and a compact size, to be integrated with the antenna. Figure 2 shows the configuration of the adopted DGS filter.

The filter is printed on a FR4 substrate ($\epsilon_r = 3.7$, $\tan \delta = 0.02$, and $h = 0.8$ mm). The total size of the filter is $0.36 \times 0.33 \lambda_0^2$, where λ_0 is the free-space wavelength at 5.5 GHz. The dimensions of the unit cell have been optimized by a means of a parametric study of the bowtie unit cell to reject the undesired band from 7 GHz up to 22 GHz.

The physical parameters of the filter, shown in Figure 2, are listed in Table 2. The simulated scattering parameters ($|S_{11}|$ and $|S_{21}|$, resp.) of the proposed filter are shown in Figure 3. They were obtained with CST Microwave Studio.

The 3 dB cut-off frequency of the filter is 5.5 GHz and the rejected band is between 7 GHz and 22 GHz (103%) for a $|S_{21}|$ less than –15 dB.

FIGURE 3: Magnitude of the filter scattering parameters versus frequency.

FIGURE 4: Geometry of the proposed antenna.

FIGURE 5: Prototype of the proposed antenna.

FIGURE 6: Magnitude of the antenna scattering parameters versus frequency.

FIGURE 7: Simulated and measured radiation pattern in the H-plane (xoz) (10 dB/div).

TABLE 2: Physical parameters of the filter.

Parameters	Values (mm)	Parameters	Values (mm)
$L_{f_{sub}}$	20	Wb1	6.15
$W_{f_{sub}}$	18	Wb2	4.9
e	0.5	Wb3	2.6
$g1$	0.8	lb1	3.1
$g2$	0.3	lb2	2.5
b	0.3	lb3	1.36

TABLE 3: Physical parameters of the complete structure.

Parameters	Values (mm)	Parameters	Values
L_{sub}	67	r	12 mm
w_{sub}	67	α	43°
h	14	w_1	0.3 mm
b	11.8	t	4.6 mm
a	19.4	lt_1	12 mm
lt	14		

3. The Proposed Antenna

The complete structure is composed of a dual-polarized antenna within which the DGS filter is inserted (see Figure 4).

The antenna is formed by two bowtie radiating elements. One radiating element is printed on the top of the substrate (FR4, $\epsilon_r = 3.7$, $\tan \delta = 0.02$, and $h = 0.8$ mm) and the other one is rotated by 90° and printed on its bottom side, without any connection between these two structures. Both elements are fed with a coplanar waveguide (CPW) through a wideband transition used as a matching circuit. This transition transforms the input impedance of the antenna, close to 160 Ω , into 50 Ω at the SMA connector. The filter is

then integrated into the feeding system. Table 3 summarizes all the dimensions of the radiating element shown in Figure 4.

The photograph of the realized dual-polarized antenna-filter is shown in Figure 5.

In Figure 6, a good agreement between computed and measured antenna scattering parameters can be observed.

From Figure 6 it appears that a bandwidth of 74% is achieved when maintaining the $|S_{11}|$ below -10 dB, which covers the required operating frequency band from 2.7 GHz to 5.9 GHz. The electrical isolation between the input ports of the dual-polarized antenna is higher than 18 dB over the whole antenna operating frequency band. Furthermore, higher harmonics are effectively suppressed. The total size

FIGURE 8: Simulated and measured radiation pattern in the E-plane (yoz) (10 dB/div).

FIGURE 9: Back-to-back configuration of the filter.

of the antenna is $0.6 \times 0.6\lambda_0^2$, where λ_0 is the free-space wavelength at 2.7 GHz.

Figures 7 and 8 illustrate the simulated and the measured copolar and cross-polar realized gain radiation patterns in the E- and H-planes at 3, 4, and 5 GHz for port 1. The port 1 is fed while the port 2 is connected to a 50Ω load.

The radiation patterns (Figures 7 and 8) show that the radiation mechanism is similar to a conventional bowtie antenna. If we consider that the antenna is fed at port 1, large surface currents are located on the edges of the vertical antenna. Due to the symmetry of each radiating element and the low level of coupling between the two ports, the x -components of the currents are in opposite phase and thus do not contribute significantly to the radiation. The y -components of the current are then responsible for the radiation and are similar to that of a half-wave dipole. This radiation mechanism occurs in the operating frequency band of the antenna, from the lowest frequency where the overall length is equal to a half wavelength to the highest frequency given by the cut-off frequency of the DGS filter. The radiation patterns in E- and H- planes (Figures 7 and 8) confirm this behavior. In H-plane (Figure 7), antenna has an omnidirectional dipole-type radiation pattern from 2.7 GHz to 5.9 GHz. In the same bandwidth, the radiation pattern in E-plane (Figure 8) is also close to the cardioid-shaped radiation pattern of a dipole. The cross-polar radiation pattern level, due to the x -components of the current, is 10 dB less than the copolar radiation pattern level, over the whole operating frequency band. The broadside realized gain varies between

3 dB and 5 dB. In H-plane, a good agreement between numerical and measurement results is achieved. In E-plane, there is a close agreement between simulated and measured patterns except at 5 GHz. This disagreement may be due to the presence of the antenna positioning mast in the anechoic chamber leading to a field perturbation.

4. General Discussion

The main disadvantage of a DGS filter is that it may radiate. In fact, the DGS structures can be viewed as a slot antenna [6]. In order to study the radiation characteristics of the DGS filter, the back-to-back configuration, as shown in Figure 9, has been numerically analyzed using CST Microwave Studio.

The comparison of the computed realized gain of the proposed antenna and that of the filter (see Figure 9) in the H- and E-plane are depicted in Figures 10 and 11, respectively.

As can be seen, both structures have the same polarization in the operating frequency band. Furthermore, Figure 12, which represents the peak realized gain versus frequency, shows that the realized gain of the filter is less than 0 dB until 21 GHz. Thus, it may be considered that the filter does not radiate efficiently at and below 21 GHz.

5. Conclusion

In this paper, a dual-polarized wideband bowtie CPW-fed antenna having wideband harmonic suppression using three

FIGURE 10: Simulated radiation pattern of the antenna and the filter in the H-plane (10 dB/div).

FIGURE 11: Simulated radiation pattern of the antenna and the filter in the E-plane (10 dB/div).

FIGURE 12: Simulated peak realized gain versus frequency of the filter in a back-to-back configuration.

nonuniform cascaded bowtie DGS unit cells has been presented. This structure provides wide bandwidth (more than an octave) and dual polarization performance. Furthermore, the antenna is interrelated to the filter and the matching circuit. The total size of the proposed structure is $0.6 \times 0.6\lambda_0^2$, where λ_0 is the free-space wavelength at the lowest frequency. The realized dual-polarized antenna operates in the

frequency range between 2.7 GHz and 5.9 GHz (bandwidth of about 74%). The harmonics are effectively rejected beyond 5.9 GHz. The measured and simulated scattering parameters are in good agreement. The antenna has an omnidirectional dipole-type radiation pattern over the operating frequency band 2.7–5.9 GHz. These characteristics allow the proposed structure to cover the UWB (lower band in Europe) and IEEE 802.16 (WiMAX).

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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