An Orthogonally Polarized Negative Resonance CRLH Patch Antenna

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Abstract – A novel fully-printed microstrip antenna with negative first resonance and dual polarization is proposed. The radiator is printed on the 1-layer substrate instead of multilayers. The -1st resonance results from a composite right- and left-handed(CRLH) structure that has a circumferentially interlocked gap capacitively coupling a patch with a shorted-ring. This compact antenna is provided with a dual-polarization capability by creating two orthogonal linear polarizations in one body with coaxial feeds. The design is carried out by doing full-wave EM field simulation which is compared with the measurement of the fabricated antenna prototype. The measured results give the gain of 5 dBi and the efficiency of 78% at the -1st resonance mode as the center frequency of a downlink channel of the bandwidth over 20 MHz with 29 dB polarization isolation for mobile communication.

Keywords: Microstrip antennas, Negative resonance, Dual-Polarized antennas, Mobile communication, Antenna feeds

1. Introduction

In the development of a wireless communication system, antennas are indispensable. Playing the role in receiving or transmitting RF signals, antennas are a crucial factor to determine the quality of the overall telecommunication system. Among various kinds of antennas, microstrip structures are popularly used for the sake of convenience in manufacturing cost, together with monopole antennas. Since the microstrip patch antenna was first introduced with the broadband radiation pattern due to the half-wavelength resonance over the patch, the basic structure has undergone a great number of modifications such as different radiator shapes from the rectangle to the triangle or circle, slots or loads, stacking with multilayers, feeding from coaxial or line connection to aperture coupling, etc to meet the needs of the desired bandwidth, beam-pattern, gain, polarization and easy installation [1,2].

To follow the users’ demands on communication channels, polarizations, radiation angles and physical sizes, numerous approaches are available to generate multiple bands, specific polarizations and directions and compact and light-weight bodies. These techniques tend to be grouped nowadays by the requirement and issues from the wireless and mobile communication industry. For example, in the area of internal antennas for handset devices, a radiator on the substrate should have more than a single resonant path for multiple bands and be put in a confined space by meandering or other schemes, for a compact geometry [3-7]. As another example, there are requests of multiple polarizations for an antenna structure to improve the versatility of wireless connection between transmitter and receiver. The polarizations are required to be created not by several independent radiators but by one body for the purpose of preventing the antenna from enlarging. These two attempts are simply for keeping the antennas as small as possible to attract more users. Notwithstanding the aforementioned efforts to make compact antennas, effects are not significant and restrictions exist in the size-reduction, since they rely on the half-wavelength resonance at the frequency of interest.

During the last few years, metamaterials and their modified forms have been adopted to play the solutions to decreased sizes as well as function improvement for antennas [8-12]. As a metamaterial, the composite right- and left-handed(CRLH)-based structure will have zeroth-order resonance(ZOR) and negative resonance as the result of adding the phase-lead of the left-handed(LH) region to the phase-delay of the right-handed(RH) due to the non-linear dispersion curve, where the negative resonance mode and ZOR are the key to the size-reduction. Leong et al showed an array of mushrooms which resonates at a lower frequency with the unit-cell much smaller than the RH half-wavelength by meeting the ZOR condition [8, 9]. The electric field in their antenna has non-phase variation and it has a monopolar radiation pattern from the microstrip patch. J. Ha et al obtained a similar behaviour of near- and far-fields from the antenna consisting of metal patches backed by the CSRR(complimentary split ring resonator)[10], which has a decreased size from the RH half-wavelength. As the ZOR antennas, tightly coupled SRRs shorted to the ground and shorted ring coupled circular patch for the MIMO and low-profile monopolar radiation, respectively, were designed [11, 12]. Looking over the metamaterial antennas above, they have one
polarization. Whether an antenna has the RH half-wavelength or metamaterial resonance, when it is applied to the repeater, the satellite communication, the elements of base-station antennas and so on, dual-polarization will be needed [13-17]. With the requirement on the compact geometry, when the dual-polarization is decided as a design objective, one radiating body should create 2 different polarizations. There are dual-polarized microstrip patch antennas reported in literatures like [13-17]. Perpendicular line-feeds attached to the ordinary patch were studied for dual-polarization[13]. Säily assigned multiple layers to the main radiator, an air-gap, orthogonal line-feeds, orthogonal slots, another air-gap, and the ground [14]. In [15] as a Ku-band antenna, one radiating patch is line-fed from port 1 for horizontal polarization and another for vertical polarization is connected to the line-feed from port 2, and they are separated in different layers. Padhi used a multilayered antenna comprising a circular patch on the top and two apertures in the middle layer above the bottom with two line-feeds [16]. ±45° polarizations are made by 2 arrays of parasitic loads and radiators excited by inverted L-shaped feeds for higher polarization isolation [17].

In this paper, a compact 1-layer microstrip antenna for dual-polarization is proposed. The size of the radiator is decreased by the negative first resonance mode as the center frequency of a downlink channel of mobile communication, due to a circumferentially interlocked gap which couples the patch and a shorted ring. This structure is coaxial-fed by 2 ports designed to generate two orthogonal linear polarizations. A full-wave simulator is employed to design the antenna, and the simulation is compared to the measurement. The measured gain, efficiency, isolation between the polarizations, and bandwidth are 5 dBi, 78%, >25dB and >20MHz, respectively, as a moderate performance for mobile communication service.

2. CRLH Antenna with the Negative Resonance Mode Balun

Before the dual-polarization is created, the design of the proposed antenna begins with the following structure and its single linear polarization.

The microstrip antenna shown in Fig. 1 is to have the negative resonance and zeroth resonance phenomena as a CRLH geometry by coupling the patch capacitively with the shorted ring through a circumferentially interlocked gap. Differing from the conventional half-wavelength based antennas with line-feeds and multi-layers for single- or dual-polarization mentioned in the introduction, the negative first resonance mode of the proposed antenna will be chosen to generate the linear polarization and broadside radiation. Though the ZOR makes the monopolar radiation pattern which is out of concern in this work, it is needed in the design process, since the -1st resonance accompanies the ZOR in our CRLH antenna. To make the proposed antenna applicable to base-station antenna elements, etc. with the advantage of a smaller footprint and low-profile, the volume of the radiator is set as 5×5×1 cm³ for one of the bands in the frequency from 1.7 GHz to 2.5 GHz. And the band 2.37 GHz and bandwidth ≥40 MHz are selected with gain ≥3 dBi and efficiency ≥70%. This means the –1st resonance mode should occur at 2.37 GHz. The antenna design is carried out by the following parametric studies to overcome the low-gain and low-efficiency problems of the negative resonance at the expense of mitigating the ZOR and positive resonance.

Each parametric sweep in Fig. 2 is based on the initial structure implemented for the equivalent CRLH circuit which has the capacitors and inductors to create both the –1st resonance and ZOR as similar to that in [11]: CR of 0.35 pF and LR of 31.80 nH from the centre patch, and CL of 0.06 pF from the capacitive gap, and LL of 11.5 nH mainly from the shorted ring. The gap becomes circumferentially symmetric interlocked(n_f pairs of fingers on each of the four equal sides and the finger length is i_l) for size-reduction and balance between orthogonal polarizations designed in the next section, and is adjusted with the vias of the structure of the size 3.5×3.5×0.317 cm³ on a εr=2.2 substrate to have its –1st resonance at 1.85 GHz. In Fig. 2(a) with n_f=3, as i_l changes from 0.8 mm to 2 mm and CL increases, the -1st resonance and ZOR frequencies are shifted downward, which also occurs to Fig. 2(b) where n_f varies from 3 to 5 with 4 vias and i_l=2 mm. In Fig. 2(c), another parametric sweep is conducted by changing n_f from 3 to 5 with 4 vias and i_l=2 mm, moving the -1st resonance as desired. So, the centre frequency and the bandwidth are obtained as 2.37 GHz and 40 MHz as in Fig. 2(d) and (e) with n_f=5, i_l=2 mm, r_w=1.8 mm, and 8 vias with v_dia=0.5 mm. The negative resonance below the ZOR that has the in-phase E-field in the geometry and monopolar far-field pattern in Fig. 2(f) is characterized with the broadside beam pattern and the E-field like the +1st resonance, given in Fig. 2(g) as a miniaturized antenna, but with the gain over 3.9 dBi, the
efficiency over 75\%, and a linear polarization. As an aspect of miniaturization, though the size-reduction effect of this proposed method looks not the same as that of the unit-cell in [8] where a ZOR antenna comprises the periodic unit-cells, our –1st resonance structure is smaller than the RH half-wavelength, but needed the size for an acceptable gain and dual-polarization. With regard to the present single polarization, it coincides with the x-axis of the Cartesian coordinates in Fig. 2.

3. Dual-Polarized antenna with the -1st resonance

In this section, the negative resonance CRLH microstrip antenna with dual-polarization is designed and measured. Firstly, the design is performed by the EM field simulator. In order to create orthogonal polarizations in our negative resonance antenna coming from the previous section, the structure needs two feeds presented as Fig. 3(a). Feed 1(Port 1) and Feed 2(Port 2) excite the x- and y-
directed polarizations, respectively. The two feeds should be located at the offset points 5 mm away from the centre of the antenna, according to the test in Fig. 3(b). We define $S_{11}$ and $S_{22}$ as the return loss of feeds 1 and 2, respectively. Like [17], the isolation between the polarizations is defined as $S_{21}$ and $S_{12}$. In Fig.’s 3(c) and (d), the -1st resonance mode frequency has the $|S_{11}|$ and $|S_{22}|$ below -10 dB for both Feeds 1 and 2. Also, the orthogonal polarizations have the isolation higher than 30 dB. When the antenna is fed at port 1, the LH half-wavelength field occurs along the x-axis and the gain>3 dBi and efficiency >75% are achieved as x-directed polarization in Fig. 3(e). The mirror effect is observed with Feed 2 on for y-axis polarization in Fig. 3(f). This antenna is fabricated and measured to verify the proposed design.

Fig.’s 4(a) is the photographs of the manufactured dual-polarized negative resonance antenna. For fabrication, the SMA connectors as Feeds 1 and 2 are attached to the back of the structure, and Taconic TLY-5 is used as the 1-layer substrate with $\varepsilon_r=2.2$ and thickness=0.317 cm. The fabricated antenna gives the return loss <-10 dB and polarization isolation>25 dB in Fig.’s 4(b) and (c) which have almost the same behaviours as the simulation in Fig. 3. The difference is that the -1st resonance moves upward by 0.5 GHz from the simulation which is similar to the frequency shift in [11], and the bandwidth becomes wider up to 35 MHz, caused by soldering bumps and lack of precision alignment, and errors from materials, printing
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and etching techniques, etc. However, the frequency band of the measured antenna can be applied to a downlink channel from 1.7 GHz to 2.5 GHz, even though there is the shift from the EM field simulation. The radiation characteristics of this antenna are measured at the –1st resonance frequency, which is 2.37 GHz and 2.36 GHz with Feed 1 and Feed 2, respectively. The antenna peak-gain and the efficiency are achieved greater than 4 dBi(5 dBi) and over 75%(78%), respectively. The radiation pattern is the broadside as designed for both x-directed polarization in Fig. 4(d) and y-axis polarization in Fig. 4(e). This represents the dual-polarization from one body of the negative resonance CRLH antenna that has one layer

Fig. 4. Measurement of the fabricated dual-polarized CRLH patch antenna: (a) Front- and back-views of the manufactured antenna; (b) S11 and S21 at the -1st resonance mode; (c) S11 and S21 at the -1st resonance mode (magnified view); (d) Excitation at feed 1 for x-axis polarization (E-field and beam pattern); (e) Excitation at feed 2 for y-axis polarization (E-field and beam pattern)

4. Conclusion

In this paper, a novel fully-printed microstrip antenna with negative first resonance and dual polarization is proposed. The radiator is printed on the 1-layer dielectric. The -1st resonance stems from a CRLH structure that has a circumferentially interlocked gap capacitively coupling a patch with a shorted-ring. This compact and low-profile antenna is provided with dual-polarization by creating two orthogonal linear polarizations in one body with coaxial feeds. The design is performed through a full-wave EM solver whose result is compared with the measurement of the fabricated antenna prototype. The measured results give the gain of 5 dBi and the efficiency of 78% at the -1st resonance mode as the centre frequency of a downlink channel of the bandwidth over 40 MHz with 29 dB polarization isolation.
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References


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