Modified series-fed dipole pair antenna using split-ring resonator directors for dual-band operation

Arun Kumar and Manisha Choudhary
Department of ECE, JECRC University, Jaipur, India

ABSTRACT
The performance of the conventional Series Fed Dipole Pair Antenna (SDP) antenna is raised by adding Split Ring Resonator (SRR). Firstly, a conventional SDP antenna that operates in the frequency range of 1.8–2.62 GHz is designed by adjusting the lengths of the dipoles and the distance between the two displays. Afterwards, a couple of SRR is mounted above the top dipole to improve the antenna performance. Compact size and increase in bandwidth and gain are attained.

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1. Introduction
Microstrip antennas (MSA) are one of the best suitable examples of such radiating systems. MSA can be optimized using various methods. Optimization is focused on either bringing down the dimensions of MSA to maintain the similar gain over a similar impedance band or by increasing the different parameters of MSA like, impedance, efficiency, gain, multiple bands and bandwidth [1]. The designing techniques of MSA give small bandwidth. Thus, to increase the antenna performance in terms of dimensions, functionality and applications, various printed antenna designs have been proposed [2]. Printed antenna designs are widely applied in radio systems and wireless applications because these antennas have a simple structure, cheap and high bandwidth. Among distinct printed antennas, SDP pair antennas are widely used because antenna using integrated balun provides high bandwidth and stable profit. SRR is a couple of concentric annular rings, both the bands are split opposite to each other. SRR behaves such as a small magnetic dipole, which is applied to increase the magnetic response of an antenna. SRR is utilized to heighten the operation of an antenna in many applications [3]. Antenna using SRR can be tuned to different frequencies inside the constrained band by changing the number of SRR Unit Cells. Applying this property sub-wavelength antenna can be designed easily [4]. A dual-band SDP with SRR working on the Global Positioning System (GPS) L1 (1.563–1.587 GHz) and 1.7–2.8 GHz frequency range was carried out and the effect of SRR was presented [5]. Multiple bands were achieved by designing a monopole SRR antenna which accesses different application of wireless communication by adjusting the point of SRR [6]. Triple band operation is accomplished by designing the asymmetric monopoly SRR antenna. The function of coupling between radiating element and SRR is responsible for multi-band operation [7,8]. In the beginning section of the proposed work, a conventional SDP pair antenna implemented for a frequency range of 1.53–2.7 GHz by adjusting the distance of the dipoles and the distance between them. Analysis of obtained results shows that the antenna has low gain and small bandwidth. In the next section, a couple of SRR is used to raise the operation of the SDP antenna in terms of bandwidth and amplification. The proposed design has dual-band operation as compared to the single band conventional antenna.

2. Antenna design
The conventional and proposed antenna is shown in Figure 1(a–c). FR4 substrate having a dielectric constant of 4.4 (loss tangent = 0.025) and a thickness $H = 1.6$ mm is used for the purported design. Initially, a conventional SDP pair antenna, which will be applied as a base antenna, is designed for operation in a frequency range of 1.7–2.7 GHz. Playing along, the measurements of the SRR director are enhanced to give double band operation in the GPS L1 (1.563–1.587 GHz) and 1.7–2.8 GHz frequency bands.

3. Mathematical expression
There are bits of calculation step that are useful when simulating the antenna [9–11]:

CONTACT Arun Kumar arun.kumar@jecrcu.edu.in/arun.kumar1986@live.com
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The initial values of $\varepsilon_{\text{reff}}$ is given as:

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{12}{W} \left( \frac{h}{W} - \frac{1}{2} \right) \right].$$  \hspace{1cm} (1)

The patch geometry alongside its span has been protracted by distance $\Delta L$, which is a function of $\varepsilon_{\text{reff}}$ and $(W/h)$.

$$\Delta L = 0.412h \left( \frac{\varepsilon_{\text{reff}} + 0.3}{\varepsilon_{\text{reff}} - 0.258} \right) \left( \frac{W}{h} + 0.264 \right) \left( \frac{W}{h} + 0.8 \right).$$ \hspace{1cm} (2)

The effective length ($L_{\text{eff}}$) becomes:

$$L_{\text{eff}} = L + 2\Delta L.$$ \hspace{1cm} (3)

The effective length for resonance frequency $f_0$, is given by

$$L_{\text{eff}} = \frac{C}{2f_0\sqrt{\varepsilon_{\text{reff}}}}.$$

Resonance frequency for $\text{TM}_{mn}$ mode is given by:

$$f_0 = \frac{C}{2\sqrt{\varepsilon_{\text{reff}}}} \left[ \left( \frac{m}{L} \right)^2 + \left( \frac{n}{W} \right)^2 \right]^{-\frac{1}{2}},$$ \hspace{1cm} (5)

where $m$ is the modes along length $(L)$ and $n$ are the modes along width $(W)$. The width is given by

$$W = \frac{C}{2f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}}.$$ \hspace{1cm} (6)

Table 1. Design parameter values of conventional and proposed antenna design.

| Parameters | Conventional antenna | Proposed antenna | Type |
|------------|----------------------|------------------|------|
| $H$        | 1.6                  | 1.6              | Substrate height |
| $L_1$      | 72                   | 72               | Length of dipole 1 |
| $L_2$      | 50.4                 | 50.4             | Length of dipole 2 |
| $L_g$      | 90                   | 90               | Length of reflector |
| $N$        | 5                    | –                | Strip length in multiples of $N$gap |
| $S_1$      | 36                   | 36               | Distance between reflector and dipole 1 |
| $S_2$      | 36                   | 36               | Distance between dipole 1 and dipole 2 |
| $W$        | 115                  | 115              | Width of substrate |
| $w_1$      | 7.5                  | 7.5              | Width of dipole 1 |
| $w_2$      | 7.5                  | 7.5              | Width of dipole 2 |
| $R_0$      | 0.5                  | 0.5              | Outer radius of feed |
| $W_{\text{gap}}$ | 20               | 20               | Width of solid |
| $g_{\text{ds}}$ | –                | 3                | Distance between $D_{\text{s}1}$ and $D_{\text{s}2}$ |
| $W_{\text{d}}$ | –                | 18               | Width of outer ring |
| $L_4$      | –                    | 18               | Length of inner ring |
| $w_{\text{d1}}$ | –                | 15               | Width of inner ring |
| $l_2$      | –                    | 15               | Length of inner ring |
| $W_{\text{e}}$ | 15               | 15               | Width of reflector |
| $D_{\text{s}}$ | –                | 13               | Distance between outer ring and dipole 1 |
| $w_{\text{e}}$ | 0.7               | 0.7              | Width of centre line |
| $W_{\text{f}}$ | –                | 3                | Width of MS |
| $X_{\text{f}}$ | –                | 3                | MS offset distance from centre |
| $Y_{\text{f}}$ | –                | 23               | Width of MS |

Table 2. Summarization of results.

| Antenna | Frequency (GHz) | Gain (dB) | Return loss (dB) | Directivity (dB) |
|---------|-----------------|-----------|------------------|------------------|
| SDP     | 1.8             | 5.99      | –22              | 6.83             |
| SDR     | 2.0             | 5.13      | –30              | 8.99             |
| SRR     | 1.58            | 7.75      | –12              | 6.83             |
| SRR     | 2.6             | 6.45      | –18              | 7.79             |
The $L$ or $W$ of ground plane is given as:

$$W_g = 6h + W,$$  \hspace{0.5cm} (7)  

$$L_g = 6h + L.$$  \hspace{0.5cm} (8)

4. Results and discussion

The study is imitated by using CST Microwave studio software and parameters utilized in the proposed and conventional antenna is given in Table 1.

The conventional antenna resonates at 1.8 and 2.62 GHz and the values of return loss at these frequencies are $-13.192$ and $-29.273$ dB, respectively. The proposed antenna resonates at 1.58 and 2.6 GHz and the values of return loss at these frequencies are $-31.15$ and $-15.35$ dB, respectively. The return loss graph of the conventional and proposed antenna is shown in Figure 2 which demonstrates that less or more power is transmitted or reflected to antenna.

The value of VSWR should be less than 2.0. If the VSWR is greater than 2.0, then more power will be reflected which can damage the radio also it cause signal distortion. For established and proposed antenna the values of VSWR are 1.56 and 1.07 at 1.8 and 2.62 GHz; 1.05 and 1.4 at 1.58 and 2.6 GHz frequency, respectively as indicated in Figure 3.
A polar plot is a diagram that depicts the magnitude of the response in any path. For the conventional design, the value of side lobe is maximum for both the resonate frequency which means it suffers from interference and power loss whereas the side lobe of the proposed antenna is minimum indicating better performance in terms of interference and power loss. The polar plot for the conventional and proposed antenna at the resonant frequency of 1.8 and 1.58 GHz is shown in Figure 4 and the polar plot for the conventional and proposed antenna at resonating frequency of 2.62 and 2.6 GHz are shown in Figure 5.

The Smith chart of the proposed antenna is also poised and is fairly matched with 50 Ω impedances of the beginning as compared to the conventional antenna. The Smith chart is too useful in the analysis of lumped elements and their matching. Smith chart of conventional and proposed design is presented in Figures 6 and 7.

5. Conclusion
A novel double band SDP antenna using split ring resonator is designed and simulated. The insight of a
parametric study of the impacts of the geometric parameters of the SRR, a form of a double band SDP antenna working in the GPS L1 (1.563–1.587 GHz) and 1.7–2.7 GHz bands were simulated and evaluated on an FR4 substrate having a dielectric constant of 4.4. The outcome shows that the antenna has a double band characteristic at 1.8 and 2.6 GHz frequency bands for a VSWR < 2. Measured gain at these frequencies is 7.75 dB in the main band and 6.49 dB in the second circle. The summarization of results is shown in Table 2.

Disclosure statement
No potential conflict of interest was reported by the authors.

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