Design of a Printed Dipole Fed by the Microstrip Line

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Abstract – The printed dipole antenna has such advantages as the compactness and the ease of feeding. A 4.3-GHz printed dipole antenna fed by the microstrip line with an integrated balun is presented. The design procedures of the dipole antenna are investigated. Performances of the quarter-wave open-stub balun and the via-hole balun are compared. Characteristics of the fabricated dipole antenna are measured and compared with the simulation.

Keywords – Integrated balun, via-hole, open-stub

I. Introduction

A microstrip open stub and via-hole balun are unbalance-to-balance transformer from the feed coaxial line to the two printed dipole arms [2]-[3]. The point 1 and 2 of the top microstrip are very close, so these phases in the top microstrip are same. The length of the dipole-arm is approximately a quarter-wavelength. The width of the dipole arm is about one-tenth of a wavelength. We used guided wavelength. Microstrip balun is about quarter-wavelength and characteristic impedance of microstrip feed line is 50 ohms [1]-[2]-[3].

Fig. 1 shows the structure of printed dipole antenna with open-stub balun and we call ‘Dipole 1’. The reflection coefficient of the printed dipole antenna with via-hole balun is compared with those of the printed dipole antenna with open-stub balun.

Fig. 2 shows the structure of printed dipole antenna with integrated via-hole balun and we call ‘Dipole 2’.

Fig. 1. A printed dipole antenna with open-stub balun (‘Dipole 1’).

Fig. 2. A printed dipole antenna with via-hole balun (‘Dipole 2’).

The dimensions of 4.3GHz printed dipole antenna with integrated balun are as follow:
PCB Substrate (FR-4): \( h=1.6 \text{mm}, \quad \varepsilon_r=4.6, \quad \tan \delta=0.018 \)
Dipole arm: \( L_d=11.5 \text{mm}, \quad W_d=2 \text{mm}, \quad g_2=2 \text{mm} \)
Microstrip balun: \( L_b=9 \text{mm}, \quad W_f=3 \text{mm}, \quad L_f=16 \text{mm}, \quad L_h=3 \text{mm}, \quad W_b=4 \text{mm}, \quad W_h=3 \text{mm}, \quad g_1=1 \text{mm} \)
Ground plane: \( L_g=4 \text{mm}, \quad W_g=15 \text{mm} \)
Via-hole: \( r=0.3 \text{mm} \)

In this paper, the design and performance of 4.3GHz printed dipole antenna with integrated balun are presented. The widely-used commercial electromagnetic software Microwave Studio™ v.
2008B is used for the numerical simulation.

II. Performance of printed dipole antenna with integrated balun

The reflection coefficient of Dipole 2 is simulated and compared with those of Dipole 1 in Figs. 3. Dipole 1 has a reflection coefficient less than -10dB over 4.05-4.51GHz (10.74% bandwidth) while Dipole 2 has a reflection coefficient less than -10dB over 3.9-4.85GHz (21.71% bandwidth).

Next, we are investigated effect of dipole length and dipole width of Dipole 2. The result is shown in Fig. 4. Those effects are same like ideal dipole antenna. When dipole length is increased, operating frequency is shifted to lower band. When dipole width is increased, bandwidth is little increased and operating frequency is shifted to lower band.

Next, we investigate the radiation pattern of Dipole 1 and 2. Fig. 5 shows 3D patterns of $G$ (total G-field), $G_{\parallel}$ and $G_{\perp}$ of Dipole 1. We have $G = 2.304$ dBi, $G_{\parallel} = 1.564$ dBi, $G_{\perp} = -1.933$ dBi.
Fig. 5. 3D pattern of $G$ (total gain) (top), $G_\varepsilon$ (middle), $G_\varepsilon$ (bottom) of Dipole 2

Fig. 6 shows the 2D patterns on $yz$-plane of Dipole 1. First, the pattern of $G_\varepsilon$ on the both the $zx$-plane has deep nulls. The pattern shape of $G_\varepsilon$ is similar to circular.

Fig. 7 shows the 2D patterns on $zx$-plane of Dipole 1. This pattern is also $E$-plane and direction of $G_\varepsilon$ is main lobe direction of Dipole 1.

Fig. 8 shows the 2D patterns on $xy$-plane of Dipole 1. First, the pattern of $G_\varepsilon$ is entirely due to the dipole current and has a circular shape. The pattern shape of $G_\varepsilon$ is don’t like to pattern of ideal dipole antenna.
Fig. 8. 2D pattern of $G_\varepsilon$ (top) and $G_\varepsilon$ (bottom) of $xy$-plane.

Next, we investigate the radiation pattern of Dipole 1. Fig. 9 shows 3D patterns of $G$ (total G-field), $G_\varepsilon$ and $G_\varepsilon$ of Dipole 2. We have $G = 2.385$ dBi, $G_\varepsilon = 2.381$ dBi, $G_\varepsilon = -6.638$ dBi.

Fig. 10 shows the 2D patterns on $yz$-plane of Dipole 2. First, the pattern of $G_\varepsilon$ on the both the $zx$-plane has deep nulls. The pattern shape of $G_\varepsilon$ is similar to circular.

Fig. 11 shows the 2D patterns on $zx$-plane of Dipole 2. This pattern is also $E$-plane and direction of $G_\varepsilon$ is main lobe direction of Dipole 1.

Fig. 12 shows the 2D patterns on $xy$-plane of Dipole 2. First, the pattern of $G_\varepsilon$ is also entirely due to the dipole current and has a circular shape. The pattern shape of $G_\varepsilon$ is similar to pattern of ideal dipole antenna.
III. Conclusions

In this paper, the design and performance of a 4.3GHz printed dipole antenna with integrated balun are presented. The reflection coefficient of a 4.3GHz printed dipole antenna with open-stub is lower than -10dB at 4.05-4.51GHz, of the a 4.3GHz printed dipole antenna with via-hole is lower than -10dB at 3.9-4.85GHz. From this result we find that the bandwidth of Dipole 2 is wider than the bandwidth of Dipole 1. When dipole arm width and dipole length are increased, bandwidth is more widely and operating central frequency is shifted to lower band.

If we use via-hole balun, pattern shape of only dipole is like to pattern of ideal dipole antenna and we can decrease effect of fed microstrip line for pattern.

References


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• Introduction
• Antenna Design
• Measurements
• Conclusions
INTRODUCTION (1)

1) Motivation

• Establish the design method of printed dipole with balun
• Printed dipole: compact antenna
• Dipole fed by microstrip line with balun: balanced two arms current and suppressed unwanted radiation from the feed line

2) Literature survey

• Jaisson (2006): printed dipole with microstrip balun
• Chen (2004): printed dipole with tapered balun
INTRODUCTION (2)

• In this work
  - Dipole fed by microstrip line with integrated balun
  - Design procedure and numerical simulation
  - Fabrication and measurements

• Simulation software: Microwave Studio™ v. 2008B.
ANTENNA DESIGN (1)

• Principles of Operation
- Two dipole types: dipole 1, dipole 2
- Dipole current: in the same direction
- Operation of balun: via-hole first, stub is similar, currents on microstrip and ground plane, its length, first part streamlined
- Ground plane: streamlined (reduced size)
ANTENNA DESIGN (2)

- Principles of Operation
  - Analysis of current distribution
ANTENNA DESIGN (3)

- Design Procedures
  - Select substrate
  - Find initial dimensions
  - Numerical simulations: parametric analyses with MWS
  - Find dimensions for low $S_{11}$ in desired frequency band
  - Check radiation patterns

- Initial dimensions
  Dipole: length $L_d=10.5\text{mm}$, width $W_d=4.17\text{mm}$, gap $g_2=3\text{mm}$
  Balun strip: width $W_b=4\text{mm}$, stub length $L_s=10.5\text{mm}$, via-hole diameter $r=3\text{mm}$
  Balun ground: lengths of 1$^{st}$ $L_g=5\text{mm}$ and 2$^{nd}$ $L_b=10.5\text{mm}$ parts, gap $g_1=1\text{mm}$
  Ground: width $W_g=15\text{mm}$
ANTENNA DESIGN (4)

- Parametric studies

VSWR vs. Dipole Length

VSWR vs. Dipole Width
ANTENNA DESIGN (5)

- Parametric studies

VSWR vs. Balun Length

![Graph showing VSWR vs. Balun Length for different lengths Lb: 8mm, 9mm, 10mm, 11mm, and 12mm. The graph plots VSWR on the y-axis and Frequency (GHz) on the x-axis. Different line styles represent each length.]
ANTENNA DESIGN (6)

- Parametric studies

VSWR vs. Balun Stub Length

- Balun stub length=6mm
- Balun stub length=7mm
- Balun stub length=8mm
- Balun stub length=9mm
- Balun stub length=10mm
- Balun stub length=11mm

Frequency (GHz)

VSWR

3.6 3.7 3.8 3.9 4.0 4.1 4.2 4.3 4.4 4.5 4.6 4.7 4.8 4.9 5.0
ANTENNA DESIGN (7)

- Result: optimum dimensions

- Substrate: FR-4 (h=1.6mm, \(\varepsilon_r=4.6\), \(\tan\delta=4.6\))
- Dipole arm: length \(L_d=11.5\)mm, width \(W_d=2\)mm, gap \(g_2=2\)mm
- Balun: length \(L_f=16\)mm, \(L_b=9\)mm, \(L_h=3\)mm, width \(w_f=3\)mm, \(w_b=4\)mm,
  \(w_h=3\)mm, gap \(g_1=1\)mm
- Ground plane: length \(L_g=4\)mm, width \(W_g=15\)mm
- Via-hole: radius \(r=0.3\)mm
ANTENNA DESIGN (8)

- Result: dipole current

Total current magnitude vs. Dipole Length

Total current phase vs. Dipole Length
ANTENNA DESIGN (9)

- Reflection coefficients

- Dipole 1: 4.05-4.51GHz  $|S_{11}| \leq -10$ dB (10.74%)
- Dipole 2: 3.9-4.85GHz  $|S_{11}| \leq -10$ dB (21.71%)

![Reflection Coefficient Graph](image-url)
ANTENNA DESIGN (10)

- 3D gain patterns of $G_{\text{total}}$ of Dipole 1 and Dipole 2

- Dipole 1: $G_{\text{max}} = 1.926$ dB
  - Type: Farfield
  - Approximation: enabled ($kR \gg 1$)
  - Monitor: Farfield ($f=4.3$) [1]
  - Component: Abs
  - Output: Gain
  - Frequency: 4.3
  - Rad. effic.: 0.9165
  - Tot. effic.: 0.8868
  - Gain: 1.926 dB

- Dipole 2: $G_{\text{max}} = 1.961$ dB
  - Type: Farfield
  - Approximation: enabled ($kR \gg 1$)
  - Monitor: farfield ($f=4.3$) [1]
  - Component: Abs
  - Output: Gain
  - Frequency: 4.3
  - Rad. effic.: 0.9069
  - Tot. effic.: 0.9014
  - Gain: 1.961 dB
ANTENNA DESIGN (11)

• 3D gain patterns of $G_{\theta}$ of both dipoles

Dipole 1: $G_{\theta_{\text{max}}} = 1.185$ dB

Dipole 2: $G_{\theta_{\text{max}}} = 1.957$ dB
ANTENNA DESIGN (12)

- 3D gain patterns of $G_\theta$ of both dipoles

- Dipole 1: $G_{\theta, \text{max}} = -2.312$ dB

- Dipole 2: $G_{\theta, \text{max}} = -7.063$ dB

- Large cross pol. components: due to radiation from feed line
ANTENNA DESIGN (13)

- 2D patterns on the yz-plane of $G_{\theta}(\theta)$ at $\theta=90^0$

- Dipole 1:
  - $G_{\theta,max} = -0.1 \text{ dB}$

- Dipole 2:
  - $G_{\theta,max} = 1.4 \text{ dB}$
ANTENNA DESIGN (14)

• 2D patterns on the $yz$-plane of $G_\theta(\theta)$ at $\theta=90^0$

![Diagram 1: Dipole 1]
- Frequency = 4.3
- Main lobe magnitude = -2.3 dB
- Main lobe direction = 101.0 deg.

![Diagram 2: Dipole 2]
- Frequency = 4.3
- Main lobe magnitude = -7.1 dB
- Main lobe direction = 0.0 deg.
- Angular width (3 dB) = 176.0 deg.

- Dipole 1:
  ✓ $G_{\phi,\text{max}} = -2.3$ dB
  ✓ Large cross pol. components: due to radiation from feed line

- Dipole 2:
  ✓ $G_{\phi,\text{max}} = -7.1$ dB
ANTENNA DESIGN (15)

- 2D patterns on the zx-plane of $G(\theta)$ at $\theta=0^\circ$

**Dipole 1:**
- $G_{\theta,\text{max}} = 1.2 \text{ dB}$
- Pattern tilt: due to radiation from feed line

**Dipole 2:**
- $G_{\theta,\text{max}} = 2.0 \text{ dB}$
ANTENNA DESIGN (16)

- 2D patterns on the $zx$-plane of $G_{\theta}(\theta)$ at $\theta=0^0$

- Dipole 1:
  - $G_{\phi,\text{max}} = -17.5 \text{ dB}$

- Dipole 2:
  - $G_{\phi,\text{max}} = -24.6 \text{ dB}$
ANTENNA DESIGN (17)

- 2D patterns on the xy-plane of $G_{\theta}(\theta)$ at $\theta = 90^0$

- Dipole 1:
  - $G_{\theta,\text{max}} = 0.8$ dB

- Dipole 2:
  - $G_{\theta,\text{max}} = 1.8$ dB
ANTENNA DESIGN (18)

- 2D patterns on the $xy$-plane of $G_\theta(\phi)$ at $\theta = 90^0$

- Dipole 1:
  ✓ $G_{\phi,\text{max}} = -2.3$ dB

- Dipole 2:
  ✓ $G_{\phi,\text{max}} = -10$ dB
MEASUREMENTS (1)

- Reflection coefficient of Dipole 1

![Graph showing reflection coefficient vs. frequency for simulation and measurement results for Dipole 1. The graph plots reflection coefficient (dB) on the y-axis and frequency (GHz) on the x-axis. The graph shows a comparison between simulation and measurement results, with the simulation results indicated by a solid line and the measurement results by a dashed line.]

- Dipole 1: $4.05$-$4.51$ GHz $|S_{11}| \leq -10$ dB ($10.74\%$)

- Measurement: $4.09$-$4.86$ GHz $|S_{11}| \leq -10$ dB ($17.2\%$)

- Dipole 1: $G = 1.926$ dB

- Measurement: $G = 1.1 \pm 1.0$ dB
MEASUREMENTS (2)

- 2D patterns of Dipole 1

Gain pattern on the $yz$-plane of $G_\theta(\theta)$ at $\theta=90^0$

Gain pattern on the $yz$-plane of $G_\theta(\theta)$ at $\theta=90^0$
MEASUREMENTS (3)

• 2D patterns of Dipole 1

Gain pattern on the $zx$-plane of $G_\square (\square)$ at $\theta = 0^0$

Gain patterns on the $zx$-plane of $G_\square (\square)$ at $\theta = 0^0$
MEASUREMENTS (4)

- 2D patterns of Dipole 1

Gain pattern on the \(xy\)-plane of \(G_\theta(\theta)\) at \(\theta=90^0\)

Gain pattern on the \(xy\)-plane of \(G_\theta(\theta)\) at \(\theta=90^0\)
CONCLUSIONS

• Design of Microstrip Fed Dipole:
  ➢ Characteristics of the fabricated dipole antenna are measured and compared with the simulation.
  ➢ When we used via-hole balun, bandwidth is wider than that open-stub balun.
  ➢ We have found that 'Dipole 2' has smaller levels of the cross-polarized radiation owing to the use of the via-hole balun.

• Microstrip-Fed Dipole: useful for many applications due to its compactness and favorable characteristics.