US Patent & Trademark Office
Patent Public Search | Text View

United States Patent Application Publication	20250266619
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	SHIH; Shih-Ping et al.

ANTENNA STRUCTURE AND BLUETOOTH ANTENNA

Abstract

An antenna structure includes a main radiation element, a first ground element, a second ground element, a carrier element, a metal cavity, a first capacitor, and a second capacitor. The first ground element includes a first connection segment, a first protruding segment, and a second protruding segment. The second ground element includes a second connection segment, a third protruding segment, and a fourth protruding segment. The main radiation element is surrounded by the first ground element and the second ground element. The first capacitor is coupled between the first protruding segment and the third protruding segment. The second capacitor is coupled between the second protruding segment and the fourth protruding segment. The metal cavity is coupled to the first connection segment and the second connection segment. The carrier element is disposed in the metal cavity.

Inventors: **SHIH; Shih-Ping (Hsinchu, TW), HSU; Tzu-Hsuan (Hsinchu, TW)**

Applicant: **Wistron NeWeb Corp.** (Hsinchu, TW)

Family ID: **1000008408494**

Appl. No.: **19/009156**

Filed: **January 03, 2025**

Foreign Application Priority Data

TW	113105963	Feb. 20, 2024

Publication Classification

Int. Cl.: **H01Q13/20** (20060101); **H01Q1/24** (20060101)

U.S. Cl.:

CPC **H01Q13/20** (20130101); H01Q1/24 (20130101)

Background/Summary

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority of Taiwan Patent Application No. 113105963 filed on Feb. 20, 2024, the entirety of which is incorporated by reference herein.

BACKGROUND OF THE DISCLOSURE

Field of the Disclosure

[0002] The disclosure generally relates to an antenna structure, and more particularly, to a wideband antenna structure.

Description of the Related Art

[0003] With the advancements being made in mobile communication technology, mobile devices such as portable computers, mobile phones, multimedia players, and other hybrid functional portable electronic devices have become more common. To satisfy consumer demand, mobile devices can usually perform wireless communication functions. Some devices cover a large wireless communication area; these include mobile phones using 2G, 3G, and LTE (Long Term Evolution) systems and using frequency bands of 700 MHZ, 850 MHz, 900 MHz, 1800 MHZ, 1900 MHZ, 2100 MHz, 2300 MHz, and 2500 MHz. Some devices cover a small wireless communication area; these include mobile phones using Wi-Fi systems and using frequency bands of 2.4 GHz, 5.2 GHz, and 5.8 GHz.

[0004] Antennas are indispensable elements for wireless communication. If an antenna used for signal reception and transmission has insufficient bandwidth, it will negatively affect the communication quality of the mobile device in which it is installed. Accordingly, it has become a critical challenge for antenna designers to design a small-size, wideband antenna structure.

BRIEF SUMMARY OF THE DISCLOSURE

[0005] In an exemplary embodiment, the disclosure is directed to an antenna structure that includes a main radiation element, a first ground element, a second ground element, a first capacitor, a second capacitor, a metal cavity, and a carrier element. The main radiation element has a feeding point. The first ground element includes a first connection segment, a first protruding segment, and a second protruding segment. The second ground element includes a second connection segment, a third protruding segment, and a fourth protruding segment. The main radiation element is coupled to the second ground element. The main radiation element is surrounded by the first ground element and the second ground element. The first capacitor is coupled between the first protruding segment and the third protruding segment. The second capacitor is coupled between the second protruding segment and the fourth protruding segment. The metal cavity is coupled to the first connection segment and the second connection segment. The carrier element is disposed in the metal cavity. The carrier element is configured to carry the main radiation element, the first protruding segment, the second protruding segment, the third protruding segment, the fourth protruding segment, the first capacitor, and the second capacitor.

[0006] In another exemplary embodiment, the disclosure is directed to a Bluetooth antenna that includes a main radiation element, a first ground element, a second ground element, a first capacitor, a second capacitor, and a metal cavity. The main radiation element has a feeding point. The first ground element includes a first connection segment, a first protruding segment, and a second protruding segment. The second ground element includes a second connection segment, a third protruding segment, and a fourth protruding segment. The main radiation element is coupled to the second ground element. The main radiation element is surrounded by the first ground element and the second ground element. The first capacitor is coupled between the first protruding segment and the third protruding segment. The second capacitor is coupled between the second protruding segment and the fourth protruding segment. The metal cavity is coupled to the first connection segment and the second connection segment.

Description

BRIEF DESCRIPTION OF DRAWINGS

[0007] The disclosure can be more fully understood by reading the subsequent detailed description and examples with references made to the accompanying drawings, wherein:

[0008] FIG. **1** is a top view of an antenna structure according to an embodiment of the disclosure;

[0009] FIG. **2** is a sectional view of an antenna structure according to an embodiment of the disclosure;

[0010] FIG. **3** is a diagram of VSWR (Voltage Standing Wave Ratio) of an antenna structure according to an embodiment of the disclosure;

[0011] FIG. **4** is a diagram of radiation gain of an antenna structure according to an embodiment of the disclosure; and

[0012] FIG. **5** is a top view of an antenna structure according to an embodiment of the disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

[0013] In order to illustrate the purposes, features and advantages of the disclosure, the embodiments and figures of the disclosure are shown in detail as follows.

[0014] Certain terms are used throughout the description and following claims to refer to particular components. As one skilled in the art will appreciate, manufacturers may refer to a component by different names. This document does not intend to distinguish between components that differ in name but not function. In the following description and in the claims, the terms “include” and “comprise” are used in an open-ended fashion, and thus should be interpreted to mean “include, but not limited to . . . ”. The term “substantially” means the value is within an acceptable error range. One skilled in the art can solve the technical problem within a predetermined error range and achieve the proposed technical performance. Also, the term “couple” is intended to mean either an indirect or direct electrical connection. Accordingly, if one device is coupled to another device, that connection may be through a direct electrical connection, or through an indirect electrical connection via other devices and connections.

[0015] The following disclosure provides many different embodiments, or examples, for implementing different features of the provided subject matter. Specific examples of components and arrangements are described below to simplify the present disclosure. These are, of course, merely examples and are not intended to be limiting. For example, the formation of a first feature over or on a second feature in the description that follows may include embodiments in which the first and second features are formed in direct contact, and may also include embodiments in which additional features may be formed between the first and second features, such that the first and second features may not be in direct contact. In addition, the present disclosure may repeat reference numerals and/or letters in the various examples. This repetition is for the purpose of simplicity and clarity and does not in itself dictate a relationship between the various embodiments and/or configurations discussed.

[0016] Furthermore, spatially relative terms, such as “beneath,” “below,” “lower,” “above,” “upper” and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. The spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. The apparatus may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein may likewise be interpreted accordingly.

[0017] FIG. **1** is a top view of an antenna structure **100** according to an embodiment of the disclosure. FIG. **2** is a sectional view of the antenna structure **100** according to an embodiment of the disclosure (along a sectional line LC**1** of FIG. **1**). Please refer to FIG. **1** and FIG. **2** together. The antenna structure **100** may be applied to a mobile device, such as a smart phone, a tablet computer, or a notebook computer. In the embodiment of FIG. **1** and FIG. **2**, the antenna structure **100** includes a main radiation element **110**, a first ground element **210**, a second ground element **220**, a carrier element **260**, a metal cavity **270**, a first capacitor C**1**, and a second capacitor C**2**. The main radiation element **110**, the first ground element **210**, and the second ground element **220** may all be made of metal materials, such as copper, silver, aluminum, iron, or their alloys.

[0018] The first ground element **210** includes a first connection segment **213**, a first protruding segment **214**, and a second protruding segment **215**. The first connection segment **213** is coupled between the first protruding segment **214** and the second protruding segment **215**. In some embodiments, the first ground element **210** substantially has a x-shape, but it is not limited thereto.

[0019] The second ground element **220** includes a second connection segment **223**, a third protruding segment **224**, and a fourth protruding segment **225**. The second connection segment **223** is coupled between the third protruding segment **224** and the fourth protruding segment **225**. In some embodiments, the second ground element **220** substantially has an inverted x-shape, but it is not limited thereto.

[0020] The third protruding segment **224** is disposed opposite to the first protruding segment **214**. For example, the width W**1** of the first protruding segment **214** may be greater than the width W**3** of the third protruding segment **224**. The first capacitor C**1** is coupled between the first protruding segment **214** and the third protruding segment **224**. In some embodiments, the first capacitor C**1** has a first terminal coupled to a first connection point CP**1** on a first edge **216** of the first protruding segment **214**, and a second terminal coupled to a third connection point CP**3** on a third edge **226** of the third protruding segment **224**. However, the disclosure is not limited thereto. In alternative embodiments, based on different environments and design requirements, the width W**1** of the first protruding segment **214** and the width W**3** of the third protruding segment **224** are substantially equal to each other.

[0021] The fourth protruding segment **225** is disposed opposite to the second protruding segment **215**. For example, the second protruding segment **215** may have a variable-width shape, and the maximum width W**2** of the second protruding segment **215** may be greater than the width W**4** of the fourth protruding segment **225**. The second capacitor C**2** is coupled between the second protruding segment **215** and the fourth protruding segment **225**. In some embodiments, the second capacitor C**2** has a first terminal coupled to a second connection point CP**2** on a second edge **218** of the second protruding segment **215**, and a second terminal coupled to a fourth connection point CP**4** on a fourth edge **228** of the fourth protruding segment **225**. However, the disclosure is not limited thereto. In alternative embodiments, based on different environments and design requirements, the width W**2** of the second protruding segment **215** and the width W**4** of the fourth protruding segment **225** are substantially equal to each other.

[0022] In some embodiments, the first protruding segment **214** has a first notch **217**, the second protruding segment **215** has a second notch **219**, the third protruding segment **224** has a third notch **227**, and the fourth protruding segment **225** has a fourth notch **229**. For example, the third notch **227** may be substantially aligned with the first notch **217**, and both the first notch **217** and the third notch **227** may be disposed adjacent to the first capacitor C**1**. In addition, the fourth notch **229** may be substantially aligned with the second notch **219**, and both the second notch **219** and the fourth notch **229** may be disposed adjacent to the second capacitor C**2**. It should be noted that the term “adjacent” or “close” over the disclosure means that the distance (spacing) between two corresponding elements is smaller than a predetermined distance (e.g., 10 mm or the shorter), or means that the two corresponding elements directly touch each other (i.e., the aforementioned distance/spacing between them is reduced to 0).

[0023] In some embodiments, the first notch **217**, the second notch **219**, the third notch **227**, and the fourth notch **229** as mentioned above can help to precisely position the first capacitor C**1** and the second capacitor C**2**. In other words, they can reduce the difficulty of assembling the antenna structure **100**, especially for the soldering process of each capacitor.

[0024] The main radiation element **110** is surrounded by the first ground element **210** and the second ground element **220**. Specifically, the main radiation element **110** has a first end **111** and a second end **112**. A feeding point FP is positioned at the first end **111** of the main radiation element **110**. The second end **112** of the main radiation element **110** is coupled to the second ground element **220**. The feeding point FP may be further coupled to a signal source **190**. For example, the aforementioned signal source **190** may be an RF (Radio Frequency) module for exciting the antenna structure **100**. In some embodiments, the main radiation element **110** includes a first portion **120** adjacent to the first end **111**, a second portion **130**, and a third portion **140** adjacent to the second end **112**.

[0025] The first portion **120** of the main radiation element **110** is coupled to the feeding point FP. For example, the first portion **120** of the main radiation element **110** may substantially have an N-shape, but it is not limited thereto.

[0026] Among the main radiation element **110**, the second portion **130** is coupled between the first portion **120** and the third portion **140**. For example, the second portion **130** of the main radiation element **110** may substantially have a straight-line shape, but it is not limited thereto. In some embodiments, a first slot region **160** is defined between the first portion **120** and the second portion **130** of the main radiation element **110**, and it belongs to an open slot.

[0027] The third portion **140** of the main radiation element **110** is coupled to the second connection segment **223** and the fourth protruding segment **225**. For example, the third portion **140** of the main radiation element **110** may substantially have a variable-width slash shape, but it is not limited thereto. In some embodiments, a second slot region **170** is defined between the third portion **140** of the main radiation element **110** and the fourth protruding segment **225**, and it belongs to another open slot. In some embodiments, an acute angle θ is formed between the third portion **140** of the main radiation element **110** and the second connection segment **223**.

[0028] In some embodiments, the main radiation element **110** further includes a widening portion **150** coupled to the second portion **130**, and the widening portion **150** substantially has a rectangular shape or a square shape. The widening portion **150** of the main radiation element **110** is adjacent to the first protruding segment **214**. A first coupling gap GC**1** may be formed between the widening portion **150** of the main radiation element **110** and the first protruding segment **214**. In addition, the second portion **130** of the main radiation element **110** is adjacent to the first connection segment **213**. A second coupling gap GC**2** may be formed between the second portion **130** of the main radiation element **110** and the first connection segment **213**.

[0029] The carrier element **260** is disposed in the metal cavity **270**. For example, the carrier element **260** may be implemented with a plastic support element, which may substantially have a cuboid shape. Specifically, the carrier element **260** has a first surface E**1**, a second surface E**2**, a third surface E**3**, and a fourth surface E**4**. The first surface E**1** of the carrier element **260** is configured to carry the main radiation element **110**, the first protruding segment **214**, the second protruding segment **215**, the third protruding segment **224**, the fourth protruding segment **225**, the first capacitor C**1**, and the second capacitor C**2**. The metal cavity **270** is coupled to the first connection segment **213** and the second connection segment **223**. Also, the metal cavity **270** is distributed over the second surface E**2**, the third surface E**3**, and the third surface E**4** of the carrier element **260**. In other words, the metal cavity **270** may include a front metal plane, a back metal plane, and a bottom metal plane. The bottom metal plane may be coupled between the front metal plane and the back metal plane. In alternative embodiments, the metal cavity **270** neither includes any left metal plane nor includes any right metal plane (i.e., each of the left and right sides of the metal cavity **270** may be an open side). However, the disclosure is not limited thereto. In alternative embodiments, the carrier element **260** is implemented with an FR4 (Flame Retardant 4) substrate, a

PCB (Printed Circuit Board), or an FPC (Flexible Printed Circuit).
[0030] FIG. **3** is a diagram of VSWR (Voltage Standing Wave Ratio) of the antenna structure **100** according to an embodiment of the disclosure. The horizontal axis represents the operational frequency (MHz), and the vertical axis represents the VSWR. As shown in FIG. **3**, a first curve CC**1** represents the operational characteristic of the antenna structure **100** without using any capacitors, a second curve CC**2** represents the operational characteristic of the antenna structure **100** merely using the first capacitor C**1**, a third curve CC**3** represents the operational characteristic of the antenna structure **100** merely using the second capacitor C**2**, and a fourth curve CC**4** represents the operational characteristic of the proposed antenna structure **100** using both the first capacitor C**1** and the second capacitor C**2**. According to the measurement of FIG. **3**, the proposed antenna structure **100** can cover at least one operational frequency band FB. For example, the operational frequency band FB may be from 2400 MHz to 2500 MHz. Therefore, the antenna structure **100** of the disclosure can support at least the wideband operations of WLAN (Wireless Local Area Networks) 2.4 GHz and Bluetooth.
[0031] In some embodiments, the operational principles of the antenna structure **100** will be described as follows. The main radiation element **110** can be excited to generate the operational frequency band FB. Specifically, the operational frequency band FB is controlled by a main resonant mode **310** and an auxiliary resonant mode **320**. The second capacitor C**2** contributes to the main resonant mode **310**. The first capacitor C**1** contributes to the auxiliary resonant mode **320**. According to practical measurements, the frequency shift of the main resonant mode **310** can be appropriately adjusted by changing the shapes and sizes of the first slot region **160** and the second slot region **170**. The first coupling gap GC**1** and the second coupling gap GC**2** are used to increase the bandwidth of the operational frequency band FB. In addition, because the main radiation element **110** is surrounded by the first ground element **210**, the second ground element **220**, and the metal cavity **270**, the radiation performance of the antenna structure **100** does not tend to be negatively affected by environmental noise or interference.
[0032] FIG. **4** is a diagram of radiation gain of the antenna structure **100** according to an embodiment of the disclosure. The horizontal axis represents the operational frequency (MHz), and the vertical axis represents the radiation gain (dB). According to the measurements of FIG. **4**, the radiation gain of the antenna structure **100** can reach about −8 dB or higher within the aforementioned operational frequency band FB, and it can meet the requirements of practical applications of general mobile communication devices. It should be understood that the auxiliary resonant mode **320** almost has no corresponding radiation gain.
[0033] In some embodiments, the element sizes and element parameters of the antenna structure **100** will be described as follows. The length LM of the main radiation element **110** may be substantially equal to 0.25 wavelength (λ/4) of the operational frequency band FB of the antenna structure **100**. The length LA of the first slot region **160** may be from 2 mm to 4 mm. The width WA of the first slot region **160** may be from 3 mm to 5 mm. The length LB of the second slot region **170** may be from 0 mm to 5 mm. The width WB of the second slot region **170** may be from 1 mm to 2.5 mm. The width of the first coupling gap GC**1** may be from 1 mm to 2.5 mm. The width of the second coupling gap GC**2** may be smaller than or equal to 1 mm. The length L**1** of the first notch **217** may be from 0.1 mm to 0.3 mm. The length L**2** of the second notch **219** may be from 0.1 mm to 0.3 mm. The length L**3** of the third notch **227** may be from 0.1 mm to 0.3 mm. The length L**4** of the fourth notch **229** may be from 0.1 mm to 0.3 mm. The distance D**1** between the first connection segment **213** and the second connection segment **223** may be from 7 mm to 9 mm. The capacitance of the first capacitor C**1** may be from 0.5 pF to 0.8 pF. The capacitance of the second capacitor C**2** may be from 0.5 pF to 0.8 pF. The angle θ may be from 30 to 60 degrees, such as about 40, 45, or 50 degrees. The height H**1** of the metal cavity **270** (or the distance between the first surface E**1** and the third surface E**3** of the carrier element **260**) may be from 3 mm to 4 mm. The distance D**2** between the third protruding segment **224** and the widening portion **150** of the

main radiation element **110** may be from 1 mm to 2.5 mm. The above ranges of element sizes and element parameters are calculated and obtained according to many experiment results, and they help to optimize the operational bandwidth and impedance matching of the antenna structure **100**, and also to minimize the noise and interference of the antenna structure **100**.

[0034] In alternative embodiments, the antenna structure **100** is called as a Bluetooth antenna, but it is not necessary to include the aforementioned carrier element **260**.

[0035] FIG. **5** is a top view of an antenna structure **500** according to an embodiment of the disclosure. FIG. **5** is similar to FIG. **1**. In the embodiment of FIG. **5**, a main radiation element **510** of the antenna structure **500** further includes an extension portion **580**, which is coupled to the first portion **120** of the main radiation element **510**. For example, the extension portion **580** of the main radiation element **510** may substantially have another rectangular shape or another square shape. According to practical measurements, the extension portion **580** of the main radiation element **510** is also used to fine-tune the impedance matching of the antenna structure **500**. Other features of the antenna structure **500** of FIG. **5** are similar to those of the antenna structure **100** of FIG. **1**. Accordingly, the two embodiments can achieve similar levels of performance.

[0036] The disclosure proposes a novel antenna structure and a novel Bluetooth antenna. In comparison to the conventional design, the disclosure has at least the advantages of small size, wide bandwidth, high communication quality, and suppressing environmental noise. Therefore, the disclosure is suitable for applications in a variety of communication devices.

[0037] Note that the above element sizes, element shapes, element parameters, and frequency ranges are not limitations of the disclosure. An antenna designer can fine-tune these settings or values in order to meet specific requirements. It should be understood that the antenna structure and the Bluetooth antenna of the disclosure are not limited to the configurations depicted in FIGS. **1-5**. The disclosure may merely include any one or more features of any one or more embodiments of FIGS. **1-5**. In other words, not all of the features displayed in the figures should be implemented in the antenna structure and the Bluetooth antenna of the disclosure.

[0038] Use of ordinal terms such as “first”, “second”, “third”, etc., in the claims to modify a claim element does not by itself connote any priority, precedence, or order of one claim element over another or the temporal order in which acts of a method are performed, but are used merely as labels to distinguish one claim element having a certain name from another element having the same name (but for use of the ordinal term) to distinguish the claim elements.

[0039] While the disclosure has been described by way of example and in terms of the preferred embodiments, it should be understood that the disclosure is not limited to the disclosed embodiments. On the contrary, it is intended to cover various modifications and similar arrangements (as would be apparent to those skilled in the art). Therefore, the scope of the appended claims should be accorded the broadest interpretation so as to encompass all such modifications and similar arrangements.

Claims

1. An antenna structure, comprising: a main radiation element, having a feeding point; a first ground element, comprising a first connection segment, a first protruding segment, and a second protruding segment; a second ground element, comprising a second connection segment, a third protruding segment, and a fourth protruding segment, wherein the main radiation element is coupled to the second ground element, and wherein the main radiation element is surrounded by the first ground element and the second ground element; a first capacitor, coupled between the first protruding segment and the third protruding segment; a second capacitor, coupled between the second protruding segment and the fourth protruding segment; a metal cavity, coupled to the first connection segment and the second connection segment; and a carrier element, disposed in the metal cavity, wherein the carrier element is configured to carry the main radiation element, the first protruding segment, the second protruding segment, the third protruding segment, the fourth protruding segment, the first capacitor, and the second capacitor.

2. The antenna structure as claimed in claim 1, wherein a width of the first protruding segment is greater than that of the third protruding segment.

3. The antenna structure as claimed in claim 1, wherein a width of the second protruding segment is greater than that of the fourth protruding segment.

4. The antenna structure as claimed in claim 1, wherein the first protruding segment has a first notch, the second protruding segment has a second notch, the third protruding segment has a third notch, and the fourth protruding segment has a fourth notch.

5. The antenna structure as claimed in claim 4, wherein the third notch is substantially aligned with the first notch, and the fourth notch is substantially aligned with the second notch.

6. The antenna structure as claimed in claim 1, wherein the first capacitor has a first terminal coupled to a first connection point on a first edge of the first protruding segment, and a second terminal coupled to a third connection point on a third edge of the third protruding segment.

7. The antenna structure as claimed in claim 1, wherein a capacitance of the first capacitor is from 0.5 pF to 0.8 pF.

8. The antenna structure as claimed in claim 1, wherein the second capacitor has a first terminal coupled to a second connection point on a second edge of the second protruding segment, and a second terminal coupled to a fourth connection point on a fourth edge of the fourth protruding segment.

9. The antenna structure as claimed in claim 1, wherein a capacitance of the second capacitor is from 0.5 pF to 0.8 pF.

10. The antenna structure as claimed in claim 1, wherein the main radiation element comprises a first portion, a second portion, and a third portion, wherein the first portion is coupled to the feeding point, the second portion is coupled between the first portion and the third portion, and the third portion is coupled to the second connection segment and the fourth protruding segment.

11. The antenna structure as claimed in claim 10, wherein a first slot region is defined between the first portion and the second portion of the main radiation element.

12. The antenna structure as claimed in claim 10, wherein a second slot region is defined between the third portion of the main radiation element and the fourth protruding segment.

13. The antenna structure as claimed in claim 10, wherein an acute angle is formed between the third portion of the main radiation element and the second connection segment.

14. The antenna structure as claimed in claim 10, wherein the main radiation element further comprises a widening portion coupled to the second portion.

15. The antenna structure as claimed in claim 14, wherein a first coupling gap is formed between the widening portion of the main radiation element and the first protruding segment, and wherein a width of the first coupling gap is from 1 mm to 2.5 mm.

16. The antenna structure as claimed in claim 10, wherein a second coupling gap is formed between the second portion of the main radiation element and the first connection segment, and wherein a width of the second coupling gap is smaller than or equal to 1 mm.

17. The antenna structure as claimed in claim 10, wherein the main radiation element further comprises an extension portion coupled to the first portion.

18. The antenna structure as claimed in claim 1, wherein the antenna structure covers an operational frequency band from 2400 MHz to 2500 MHz.

19. The antenna structure as claimed in claim 18, wherein a length of the main radiation element is substantially equal to 0.25 wavelength of the operational frequency band.

20. A Bluetooth antenna, comprising: a main radiation element, having a feeding point; a first ground element, comprising a first connection segment, a first protruding segment, and a second protruding segment; a second ground element, comprising a second connection segment, a third protruding segment, and a fourth protruding segment, wherein the main radiation element is coupled to the second ground element, and wherein the main radiation element is surrounded by the first ground element and the second ground element; a first capacitor, coupled between the first protruding segment and the third protruding segment; a second capacitor, coupled between the second protruding segment and the fourth protruding segment; and a metal cavity, coupled to the first connection segment and the second connection segment.