Bluetooth® Low Energy microcomputer

Design Guidelines for a Pattern Antenna

Introduction

This application note introduces an outline of antennas and a procedure and example of the design of a pattern antenna for connection with the Bluetooth® Low Energy technology compatible microcomputer (hereinafter Bluetooth Low Energy microcomputer).

Target Device (Bluetooth Low Energy microcomputer)

RL78/G1D (R5F11Axxxxx)

RX23W (R5F523Wxxxxx)

RA4W1 (R7FA4W1xxxxx)

RE01B (R7F0E01Bxxxxx)

Contents

1. OVERVIEW OF ANTENNAS

Antennas are generally classified into magnetic- and electric-field types according to the emission pattern. The typical example of the former type is the loop antenna, which is used for contactless IC cards, etc. Antennas of the electric-field type are used in longer- or long-distance communications, with examples being those for Bluetooth and wireless LAN in the case of those formed from patterns on PCBs.

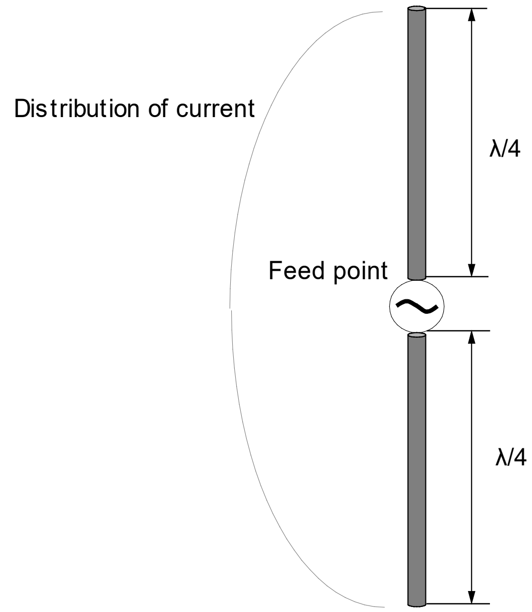
This application note describes a linear antenna of the latter type, that is, of the electric-field emission type, and is the most commonly used type of those formed by using patterns on a board.

1.1 Dipole Antenna

Both the general planar inverted-F antenna (PIFA) and meandering-line antenna are based on the principle of the dipole antenna.

Figure 1-1 shows the principle.

Figure 1-1. Principle of the Dipole Antenna



The dipole antenna is also called a half-wave antenna and consists of a signal source (feed point) with two conductors (elements) connected, each of which is a quarter of λ long (where λ is the wavelength).

If the frequency is 2.4 GHz, the value of λ can be calculated from the following formula.

$\lambda = c/f = 0.125$ m = 125 mm

λ: Wavelength in m

c: Speed of light = 3×10^8 m/s

f: Frequency = 2.4×10^9 Hz

1.2 Monopole Antenna

An antenna formed as half (i.e. a 1/4-wavelength element) of the dipole antenna described on the previous page is called a monopole antenna.

For a monopole antenna, we can consider the element on the lower side of the dipole antenna to be connected to ground as shown in figure 1-2. Changing the structure does not affect the distribution of current in the upper element. Accordingly, the antennas shown in figures 1-2 and 1-3 have equivalent characteristics.

This is called the image effect or mirror effect.

Figure 1-2. Monopole Antenna

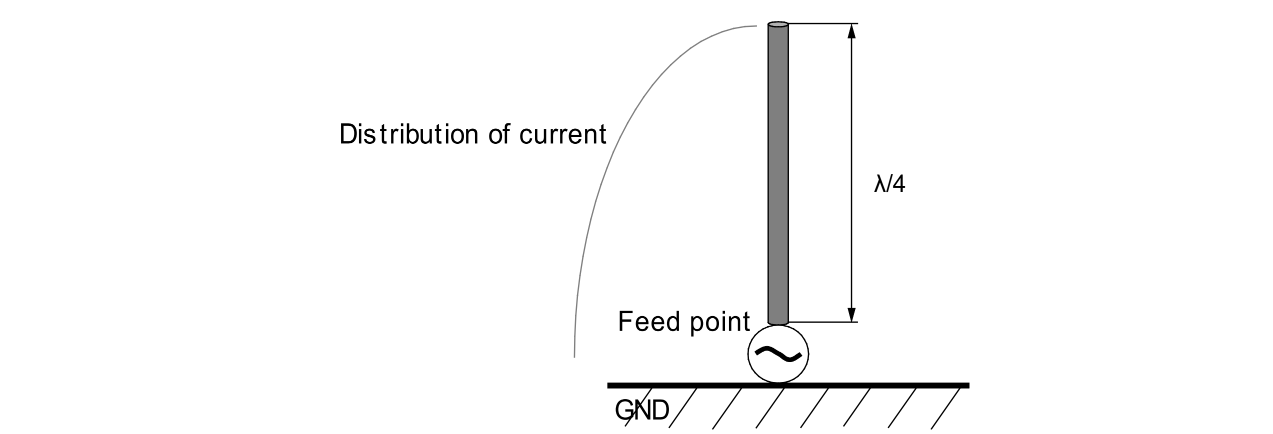
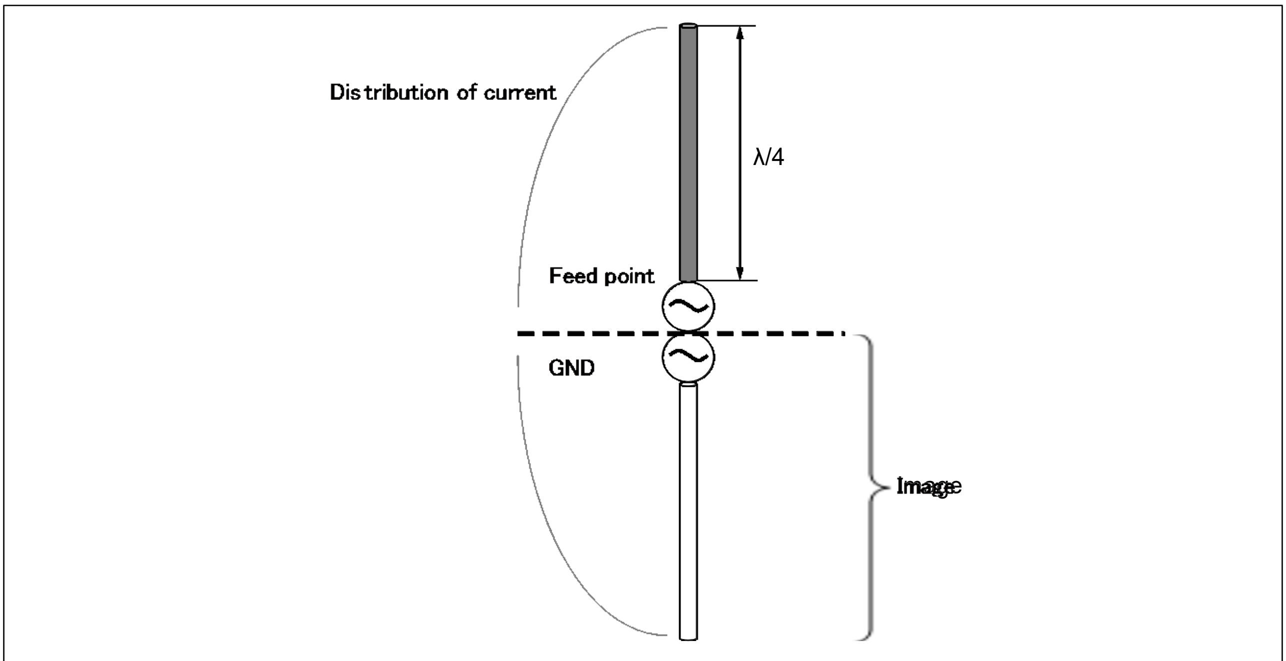


Figure 1-3. Image Effect



In order to miniaturize the antenna, the image effect is employed in most pattern and chip antennas (refer to 2.2 Small Pattern Antennas).

Caution **To obtain the image effect, the ground must be made sufficiently long and large relative to the wavelength.**

2. PATTERN ANTENNAS AND SMALL ANTENNAS

2.1 Pattern Antennas

Using a wiring pattern on a board to form a dipole antenna or monopole antenna described in 1.1 and 1.2 realizes the simplest design for such an antenna.

Recommendation The characteristics of a dipole antenna can be secured independently of the size of the ground plane. For this reason, if there are no limits on the shape and size of the antenna pattern, we recommend using a dipole.

2.2 Small Pattern Antennas

For actual designs, the dipole or monopole antenna described in 2.1 may not be usable in some cases due to limitations such as the shape of the system. In such cases, consider miniaturizing the monopole antenna by changing its shape.

The approaches to be considered in miniaturizing an antenna are given below.

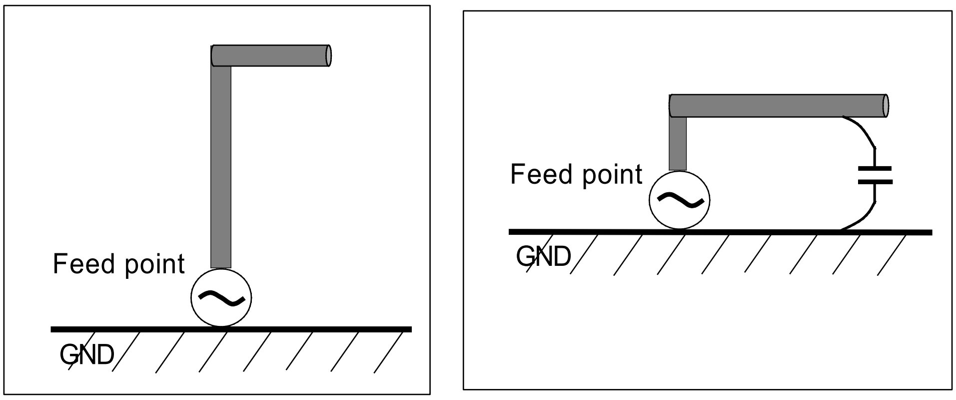
2.2.1 Inverted-L Antenna

Figure 2-1 (a) shows an example of an inverted-L monopole antenna which has a shape where the end of the monopole antenna is bent. The inverted-L shape allows the antenna to be lower.

Changing the position of the bend can further lower the antenna as shown in figure 2-1 (b). Note that the element being nearer to the ground leads to the creation of a larger capacitive component, which lowers the impedance (hereinafter referred to as Z) of the antenna. Accordingly, impedance matching by using a lumped constant or T-matching circuit may be required (refer to 6.2.2 Measurement of Impedance and Matching by Using a Lumped Constant, and 6.2.3 Matching by Using a Distributed Constant).

Figure 2-1. Inverted-L Monopole Antenna

(a) When the position of the bend is further from GND **(b) When the position of the bend is nearer GND**



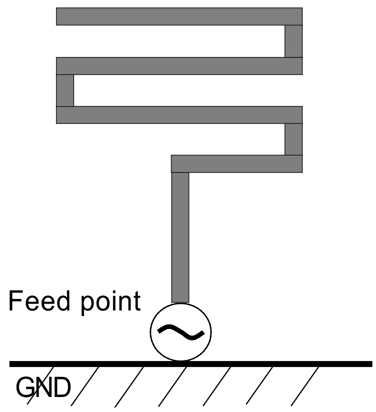
2.2.2 Horizontal Meandering-Line Antenna

Figure 2-2 shows an example of a horizontal meandering-line monopole antenna.

Repeating the inverted-L described in 2.2.1 to create a series of meandering sections can further lower an antenna.

Matching because of lowering of impedance may be required in the same way as with an inverted-L monopole antenna.

Figure 2-2. Horizontal Meandering-Line Monopole Antenna



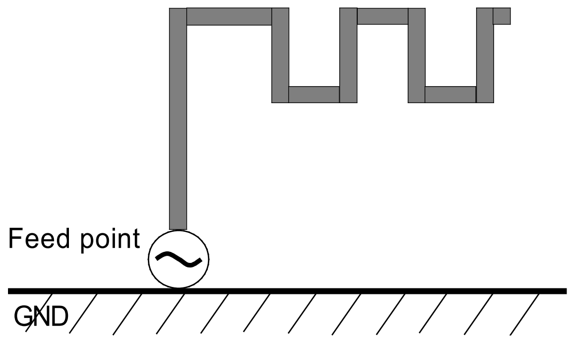
2.2.3 Vertical Meandering-Line Antenna

Figure 2-3 shows an example of a vertical meandering-line monopole antenna.

The inverted-L meandering section is repeated horizontally relative to the ground in 2.2.2. For this antenna, the inverted-L meandering section is repeated vertically relative to the ground, thereby reducing the height and size of the antenna.

Matching because of lowering of impedance may be required in the same way as with an inverted-L monopole antenna.

Figure 2-3. Vertical Meandering-Line Monopole Antenna



3. ELICITING THE REQUIRED SPECIFICATIONS OF AN ANTENNA

Before designing an antenna, the required specifications must be elicited. Selecting the most suitable antenna structure for the field of application and conditions for use and so on of the system leads to an appropriate design for the antenna.

3.1 Directional Characteristic

The directional characteristic needs to be taken into account according to the field of application of the system.

In portable equipment, for example, the direction in which the antenna is mounted cannot be fixed; the antenna may thus need to have a non-directional characteristic.

In cases where the system is fixed and used in longer-distance communications, the antenna may need to have a directional characteristic to secure ample gain.

3.2 Polarized Wave Characteristic

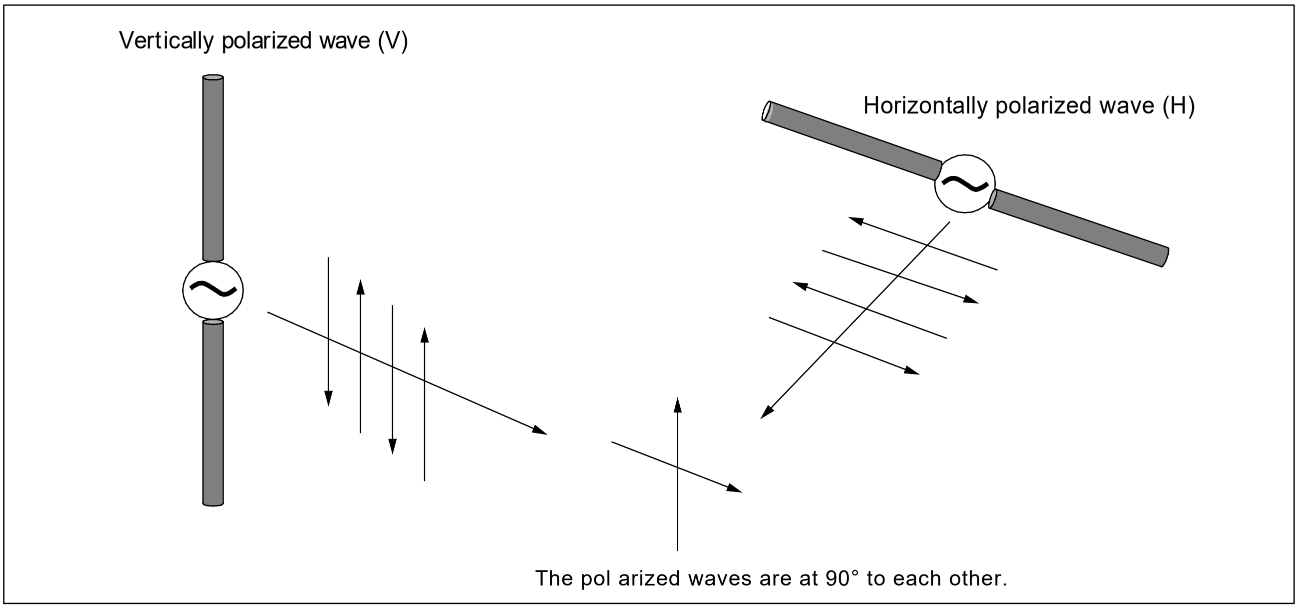
If the system is fastened in place, the direction of polarization of the waves needs to be taken into account.

When radio waves propagate through space, the magnetic field and electric field are at right angles to each other as they travel. Only with regard to the electric field, the plane of the generated field relative to the ground (GND) is called the plane of polarization of the wave. Waves in which the electric field is generated vertically and horizontally relative to the ground are referred to as vertically and horizontally polarized waves, respectively.

Figure 3-1 illustrates the relationship between vertically and horizontally polarized waves. If the planes of polarization of waves for the antenna and the antenna of the other party are at 90° to each other, the antenna gain is not obtainable.

Accordingly, for fixed equipment, the plane of polarization of waves for the antenna needs to match that of the other party to take full advantage of the antenna characteristics.

Figure 3-1. Vertically and Horizontally Polarized Waves



Although the linear antenna described in this application note has linear planes of polarization for the waves as shown above, antennas employing rotating planes of polarization are also in practical application.

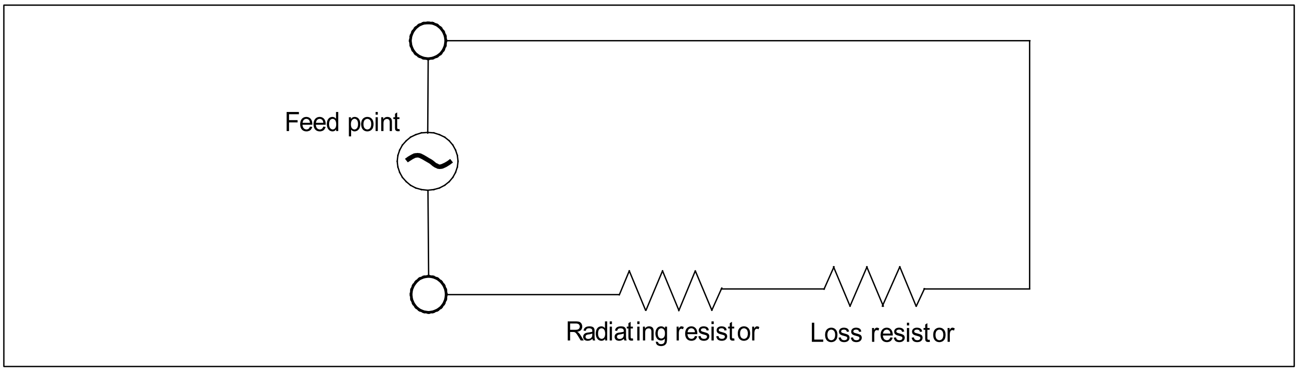
3.3 Area Available for the Antenna

The area provided for an antenna differs with conditions such as the dimensions of the board on which the IC is mounted in the system and the position where the antenna is mounted.

The position and area of the antenna must be secured from the stage of designing the structure of the system.

As shown in figure 3-2, the equivalent circuit of an antenna is composed of a radiating resistor and a loss resistor, which are connected in series. Reducing the size of an antenna increases the loss-resistance component, thus lowering the radiative efficiency. For this reason, we recommend the antenna be as large as is possible in a design to secure ample gain.

Figure 3-2. Equivalent Circuit for an Antenna



Note that the positional relation between the antenna and housing should be taken into account. For ABS (acrylonitrile butadiene styrene) housings in general, for example, locating the antenna close to the housing affects the antenna characteristics. The simplest workaround is locating the antenna away from the housing. For this reason, the volume of the system as a whole as well as the area for the antenna needs to be taken into account in design.

3.4 Required Communications Range

The communications range of a wireless system can be calculated theoretically.

Various factors determine the distance. Concrete examples are listed below.

<1> The transmission power of the IC (Pout) and sensitivity in reception (Min_sens)

<2> Power loss on the board (ILTx, ILRx)

<3> Antenna gain (GT, GR)

<4> Loss from propagation through space (PL)

<5> Spatial reflection (PL) in multipath propagation

Factor <1> can be obtained from the datasheet for the given IC.

Factor <2> differs with the board design.

Factor <3> can be obtain by measurement (refer to 4.3 Emission Characteristics).

Factor <4> can be calculated from the Friis transmission equation.

Factor <5> is not easy to calculate because it differs significantly with the use environment. However, a general method of calculation for indoor environments that includes factors <4> and <5> is proposed in ITU-R P.1238.

4. ANTENNA CHARACTERISTIC PARAMETERS AND THEIR EVALUATION

This chapter describes parameters which need to be understood in the design and evaluation of an antenna.

Parameters described in 4.1 to 4.3 are always evaluated with the antenna directly connected to a coaxial cable. The system does not have to be supplied with electric power or operating.[Note 1]

Note 1. The system may be supplied with electric power in some cases in the over the air test, the description of which is omitted from this application note.

4.1 Voltage Standing Wave Ratio (VSWR)

The voltage standing wave ratio (VSWR) is a parameter indicating the ratio of electric power input to the antenna to that input to the feed point of the antenna. A network analyzer is used to measure the VSWR in actual evaluation.

The applicable bandwidth for the Bluetooth Low Energy microcomputer is in the range from 2400 to 2480 MHz. The antenna must be designed and adjusted so that the antenna obtains the resonance frequency characteristic of VSWR < 2 or 3 over the above bandwidth.

Note that the ratio of electric power input to the antenna is approximately 89% when VSWR = 2, approximately 75% when VSWR = 3.

Figure 4-1 shows an example of the measurement result.

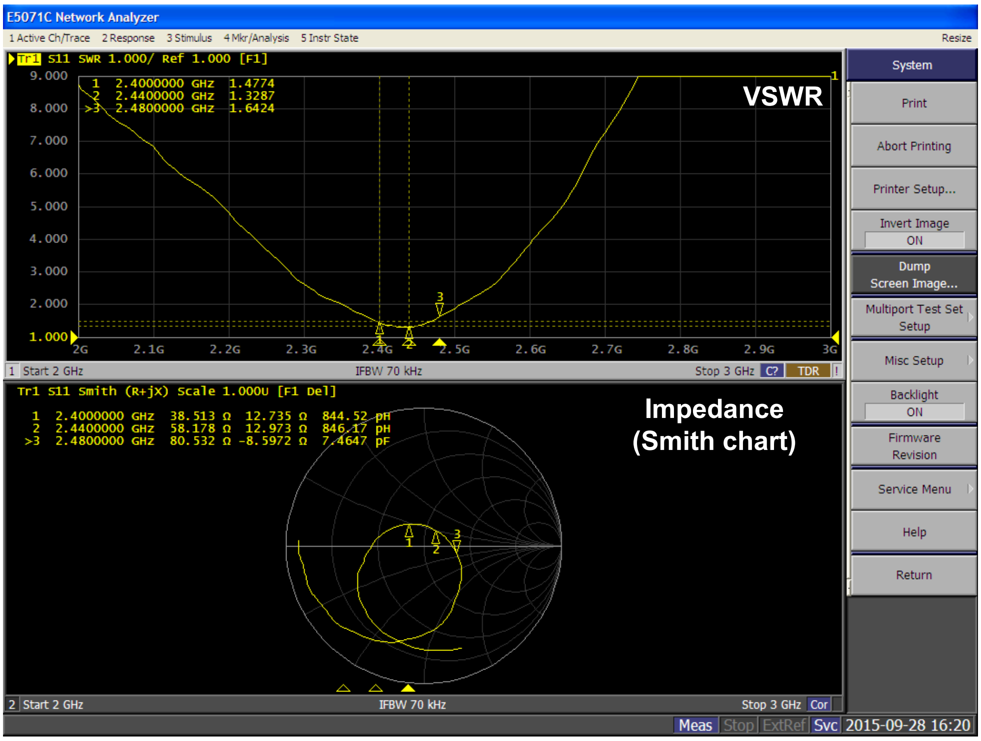
4.2 Impedance Characteristic (Smith Chart)

The impedance characteristic can be obtained by using a network analyzer to measure the S11 characteristic.

The impedance is shown as Z = R + jX, where R and X indicate the values of the real and imaginary parts, respectively. When the VSWR value is high, even if the peak resonance frequency is within the target bandwidth, the impedance, Z, diverges from 50 Ω in most cases. In such cases, the impedance needs to be brought closer to 50 Ω (to obtain antenna matching) by using Smith charts.

Figure 4-1 shows an example of the measurement result.

Figure 4-1. Example of Measuring VSWR and Impedance

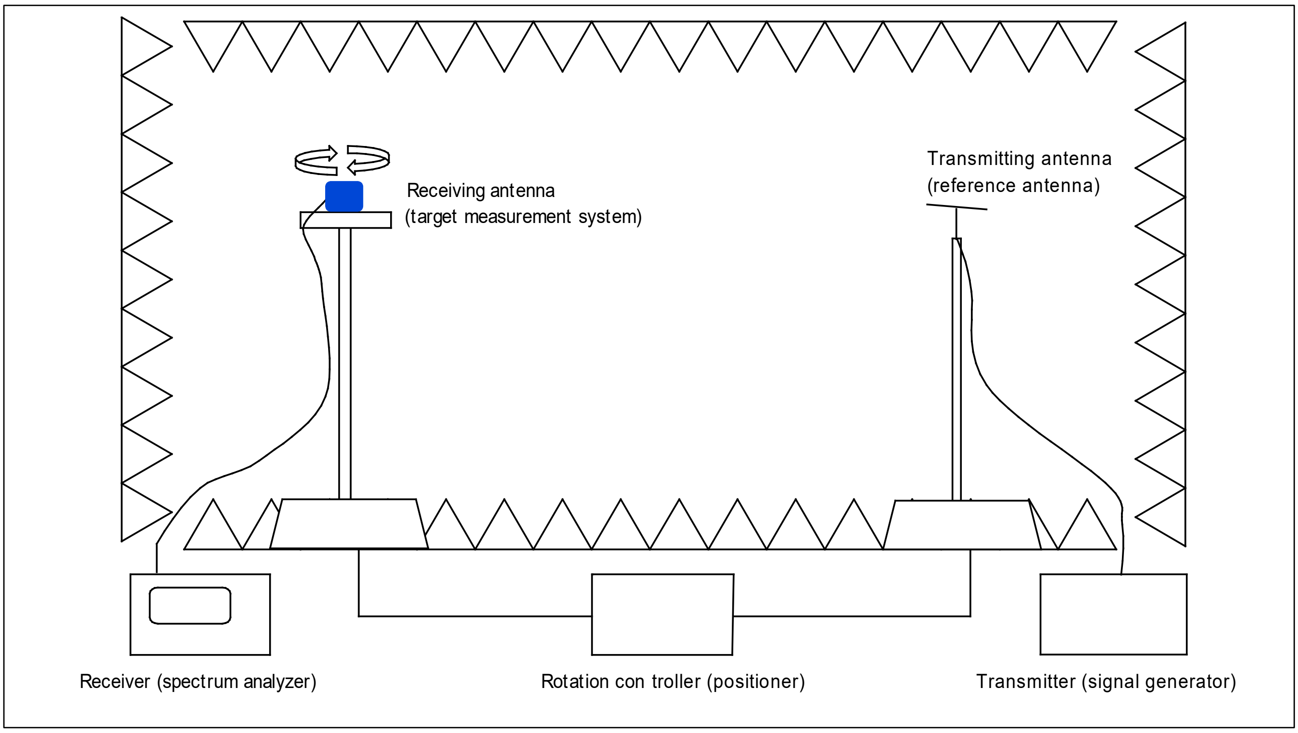


Actually, the VSWR is equivalent to the impedance, so it can be obtained by drawing an equivalent VSWR circle in a Smith chart.

4.3 Emission Characteristics

The emission of an antenna is measured in the environment shown in figure 4-2.

Figure 4-2. Environment for Measuring Emission Characteristics

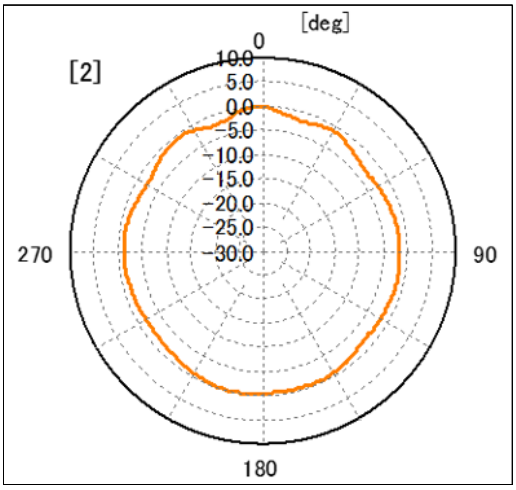


The above measurement environment form what is called a six-surface anechoic chamber, that is, shielding to avoid the reflection of radio waves in any direction is used. Private EMC measurement companies or public industrial technology institutes and so on can provide the above facility.

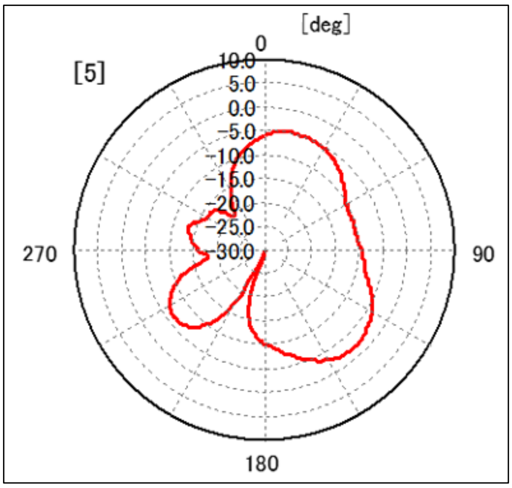
Examples of the results of the emission characteristics measurement made in a six-surface anechoic chamber are given in figure 4-3.

Figure 4-3. Examples of Results of Emission Characteristics Measurement

(a) Vertically polarized wave



(b) Horizontally polarized wave



These results are used to evaluate whether the characteristics intended for a design in terms of the average gain, the maximum gain, etc., are being obtained or not.

5. EXAMPLES OF DESIGNING SMALL PATTERN ANTENNAS

This chapter describes the structure and characteristics of three types of pattern antenna.

You can select any of them to suit the structure of your system.

5.1 Vertical Meandering-Line Antenna (Actual Measurements)

5.1.1 Features

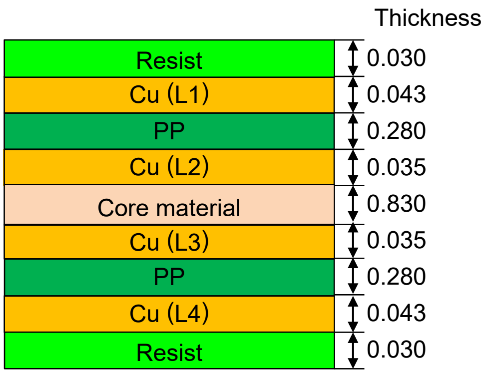
The vertical meandering-line antenna is suitable for cases where the area to be secured for the antenna is short and wide.

Dimensions of the antenna area: 7 × 33 mm

Bandwidth when VSWR < 2: Approximately 115 MHz

5.1.2 Layer Configuration of the Printed Circuit Board

Figure 5-1. Layer Configuration of the Board for the Vertical Meandering-Line Antenna



Remark Dimensions are design values.

- Board material: MCL-E-67 (FR4) (manufactured by Hitachi Chemical Co., Ltd.)
- Thickness
  - Board: 1.6 mm
  - Wiring:

    L1, L4 (Cu): 43 μm

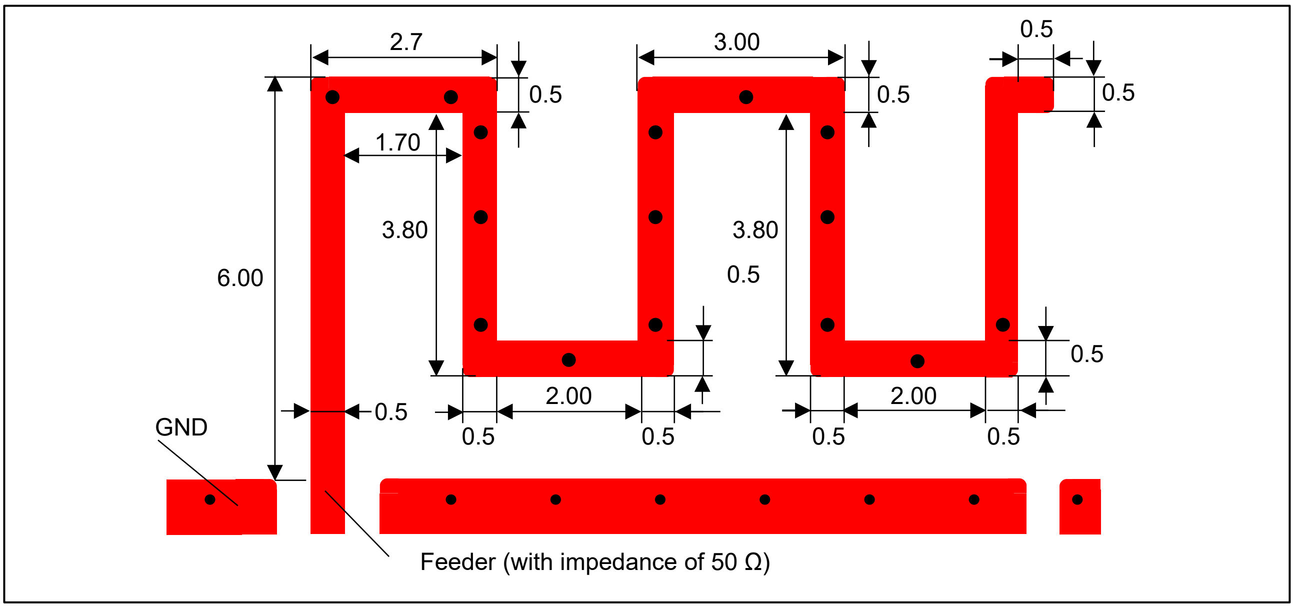
    L2, L3 (Cu): 35 μm

5.1.3 Dimensions (Top View)

Dimensions given in this section are design values (unit: mm).

Figure 5-2. Dimensions (1/2)

(a) Dimensions of the pattern antenna (in L1)



(b) Dimensions of the pattern antenna (in L4)

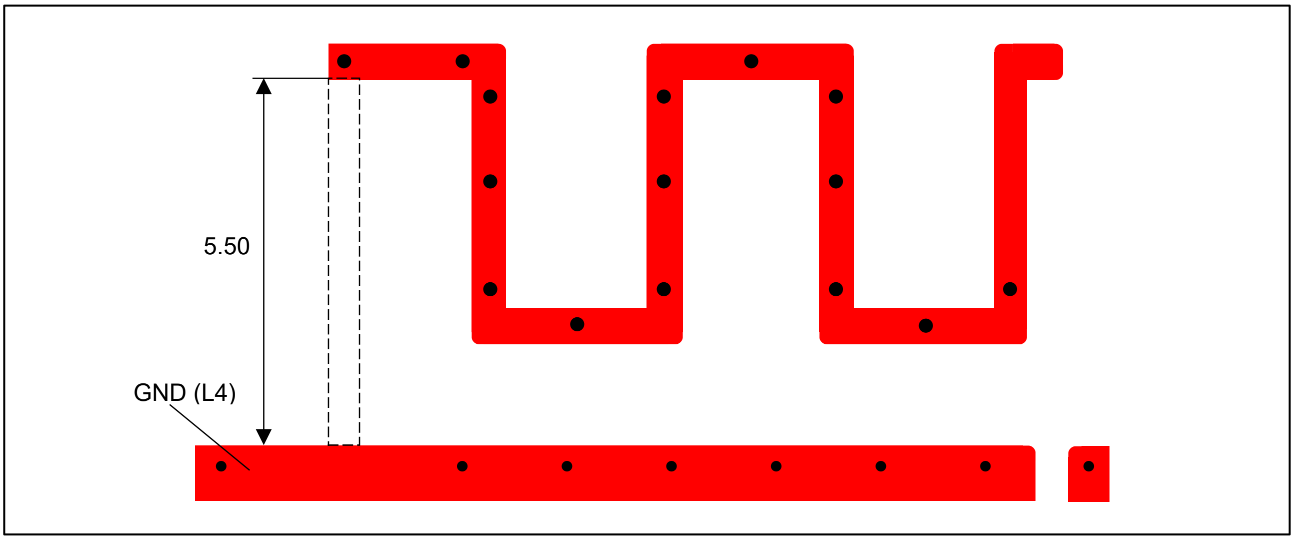
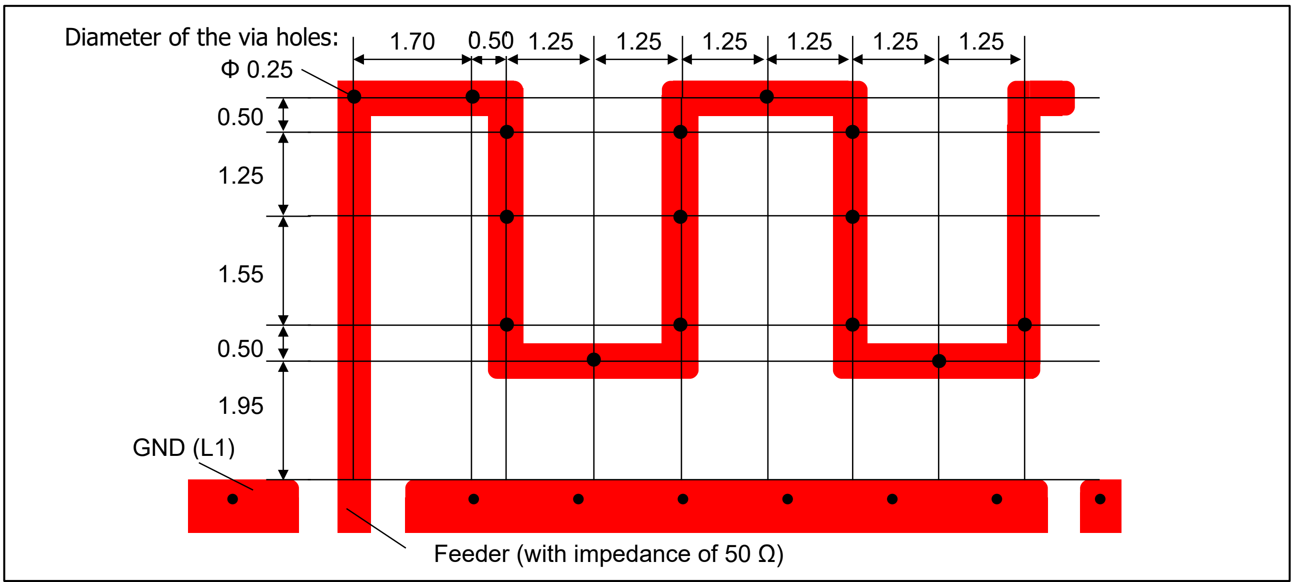


Figure 5-2. Dimensions (2/2)

(c) Locations of via holes



5.1.4 VSWR and Emission Characteristics

Figure 5-3. VSWR Characteristic

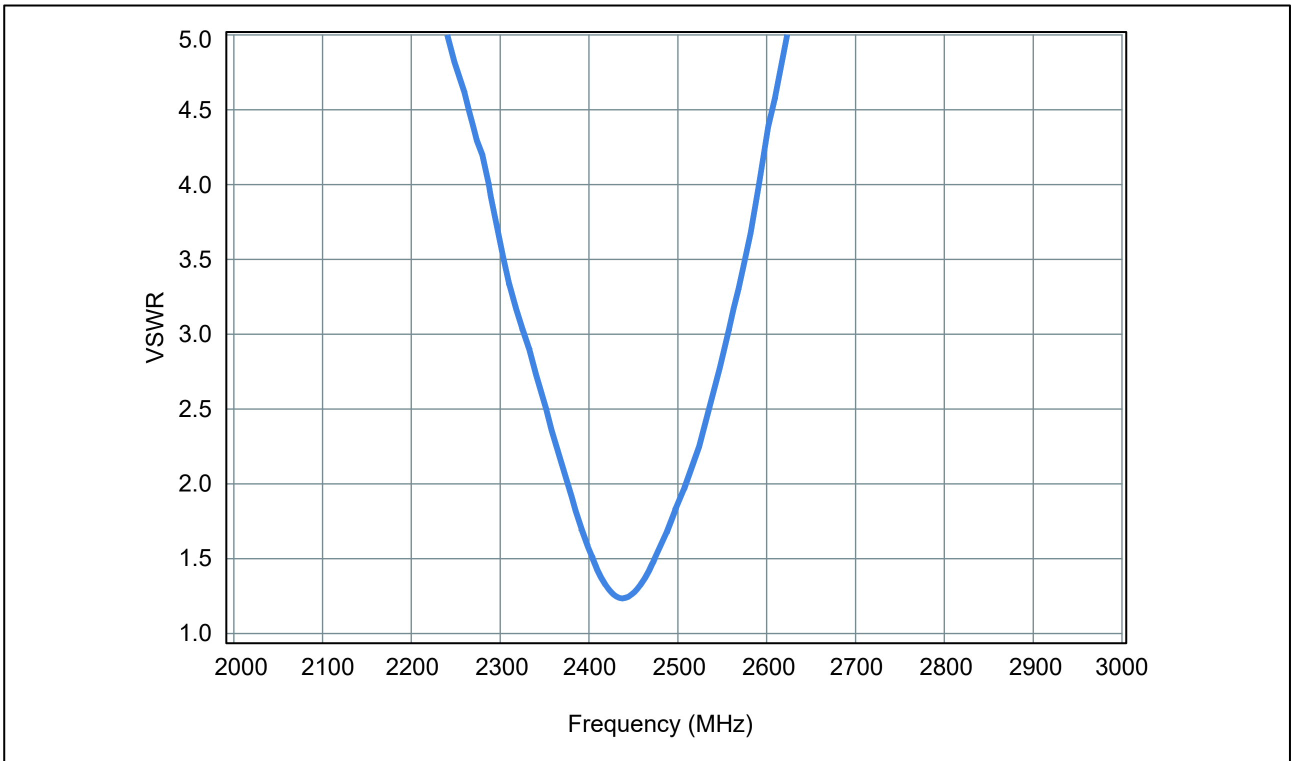


Figure 5-4 shows the coordinate axes, the positions where rotation starts (0°), and the directions of rotation of the evaluation board. The coordinate axes are defined as shown in figure 5-4 (a). The positions where rotation starts (0°) and its directions in obtaining the emission patterns in each plane are defined as shown in figure 5-4 (b).

Figure 5-4. Coordinates and Rotation of the Evaluation Board (Top View)

(a) Coordinate axes **(b) Positions where rotation starts (0°) and its directions**

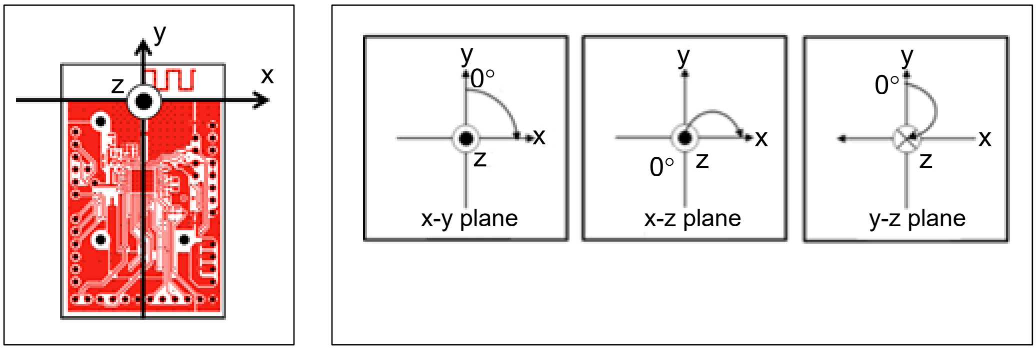
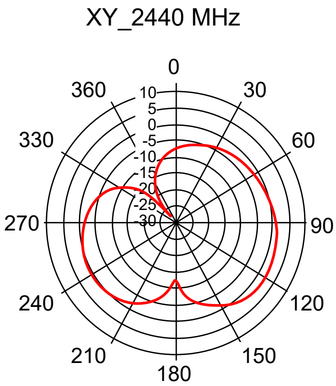
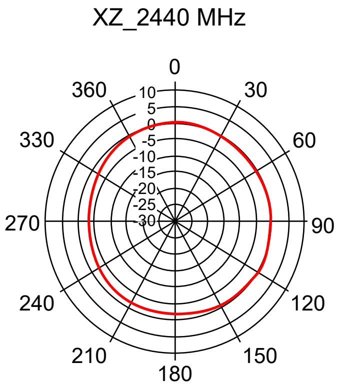
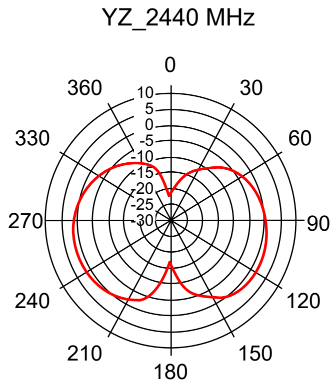


Table 5-1 shows the emission patterns and average gains measured with the antennas separated by 3 m from each other in a six-surface anechoic chamber. The measurements were made in three planes: x-y, x-z, and y-z.

Table 5-1. Emission Patterns of the Reference Antenna and Average Gains

Item	x-y Plane (Horizontally Polarized Wave)	x-z Plane (Vertically Polarized Wave)	y-z Plane (Horizontally Polarized Wave)
Emission patterns of the reference antenna			
Average gain	-2.30 dBi	-1.79 dBi	-2.30 dBi

For details on above reference antenna, see the application note, “Design of a Reference Antenna” (R01AN2652).

5.2 Thin Meandering-Line Antenna (Simulated)

5.2.1 Features

The thin meandering-line antenna is suitable for cases where the area to be secured for the antenna is long and narrow.

Having parts of the meandering structure on both sides of the board enables reduction of the area for the antenna.

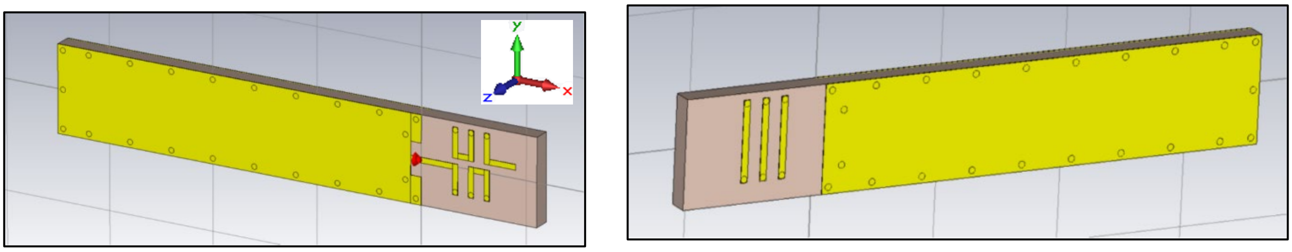
The antenna has an extremely wide bandwidth.

Dimensions of the antenna area: 8 × 11 mm

Bandwidth when VSWR < 2: Approximately 325 MHz

Figure 5-5. General Views of the Thin Meandering-Line Antenna

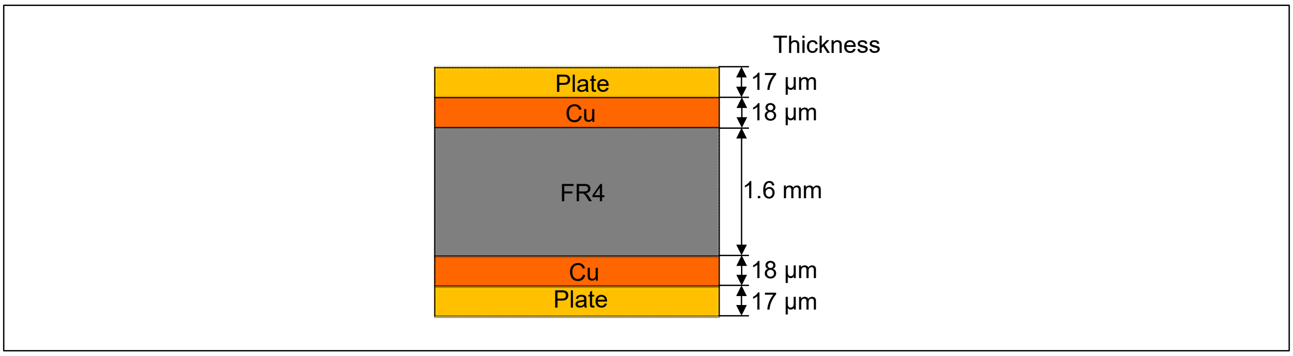
(a) L1 layer **(b) L4 layer**



5.2.2 Layer Configuration of the Printed Circuit Board

The antenna is designed on the assumption of the board configuration shown in figure 5-6.

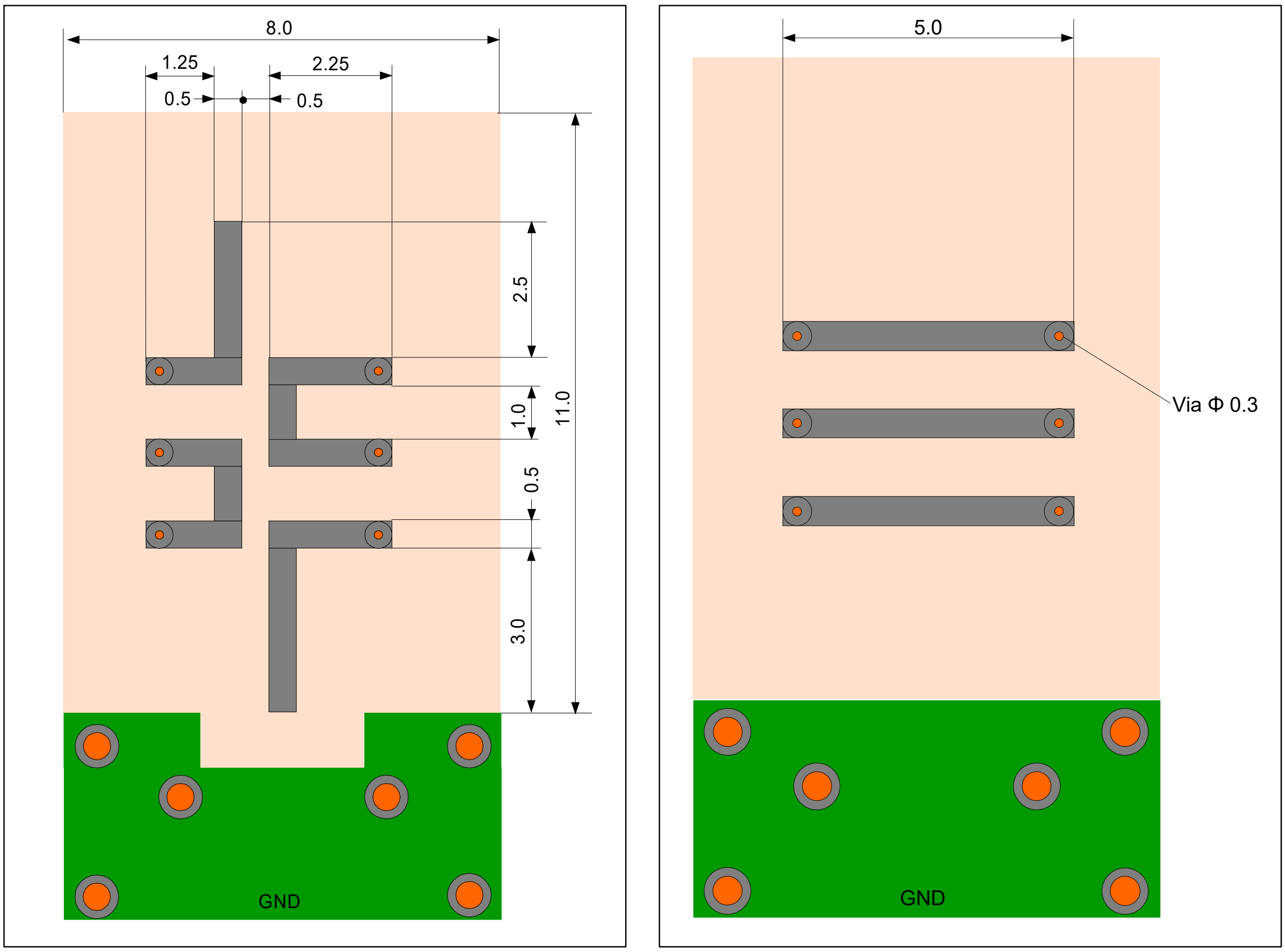
Figure 5-6. Layer Configuration of the Board for the Thin Meandering-Line Antenna



5.2.3 Dimensions of the Antenna Elements

Figure 5-7. Dimensions of the Antenna Elements (Unit: mm)

(a) L1 **(b) L4**



5.2.4 VSWR and Emission Characteristics

Figure 5-8. VSWR Characteristic

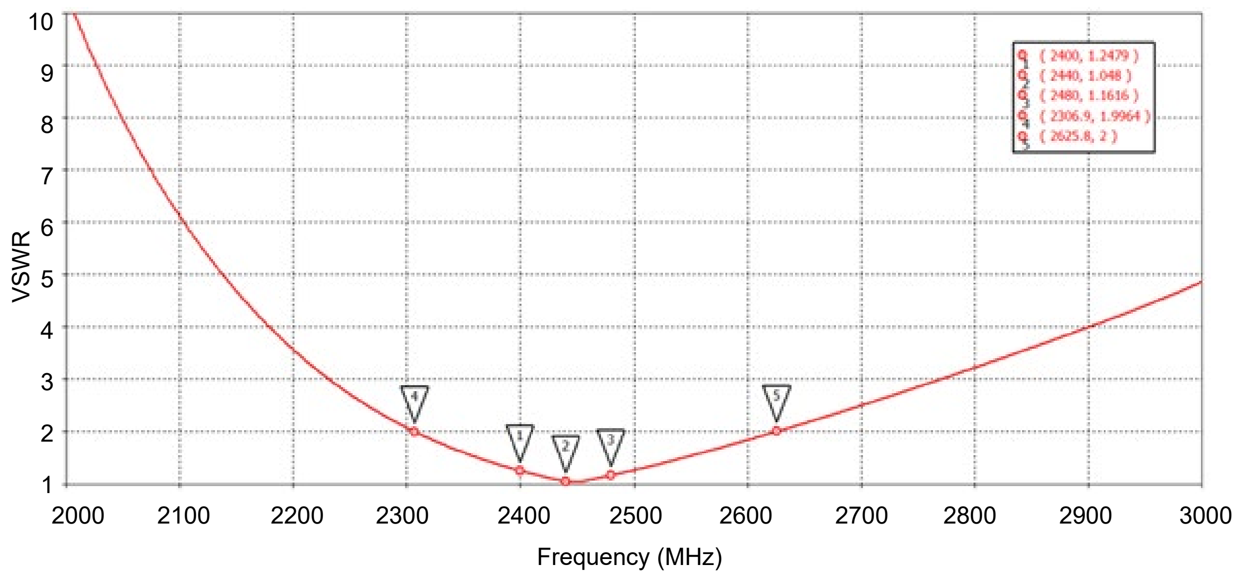
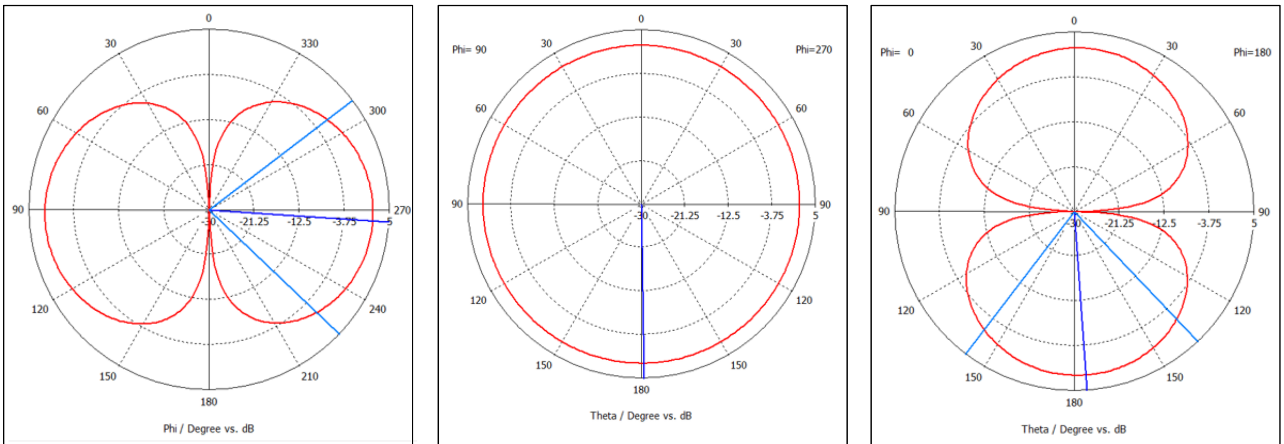


Figure 5-9. Emission Characteristics

(a) x-y plane (horizontally polarized wave)	(b) y-z plane (vertically polarized wave)	(c) x-z plane (horizontally polarized wave)



Average gain: -4.1 dBi Maximum gain: 1.9 dBi	Average gain: 2.0 dBi Maximum gain: 1.9 dBi	Average gain: -4.7 dBi Maximum gain: 1.9 dBi

5.3 Horizontal Meandering-Line Antenna (Simulated)

5.3.1 Features

The horizontal meandering-line antenna is short and small.

Having parts of the meandering structure on both sides of the board enables reduction of the area for the antenna.

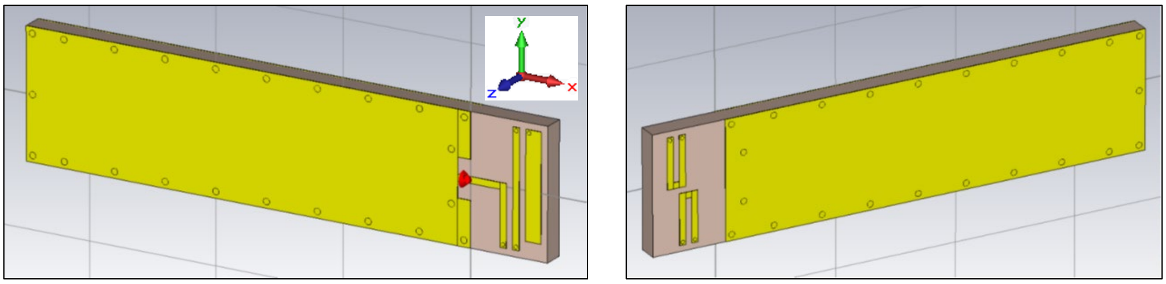
Moreover, including a capacitive hat at the top of the element enables further reduction of the area for the antenna.

Dimensions of the antenna area: 6 × 10 mm

Bandwidth when VSWR < 2: Approximately 320 MHz

Figure 5-10. General Views of the Horizontal Meandering-Line Antenna

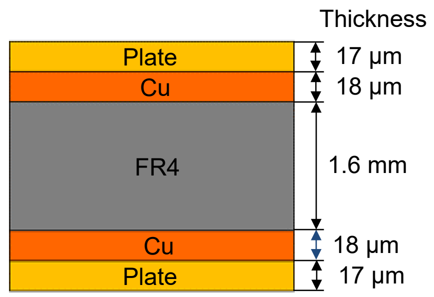
(a) L1 layer **(b) L4 layer**



5.3.2 Layer Configuration of the Printed Circuit Board

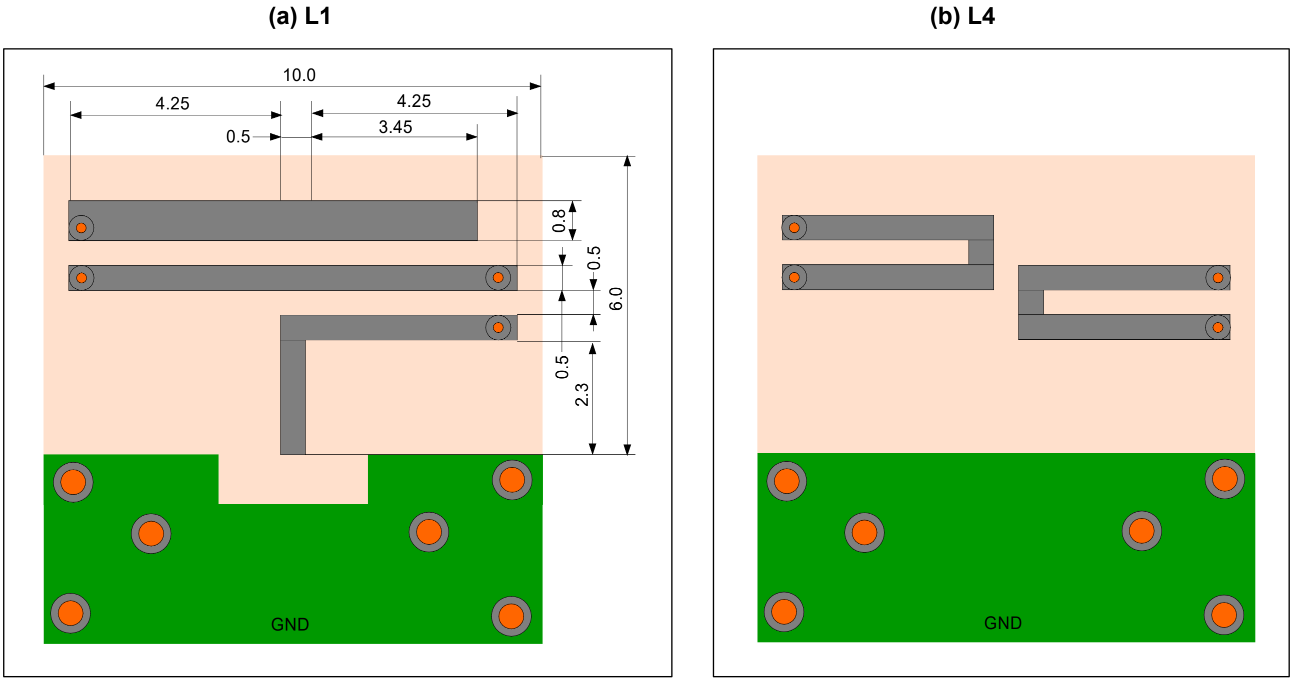
The antenna is designed on the assumption of the board configuration shown in figure 5-11.

Figure 5-11. Layer Configuration of the Board for the Horizontal Meandering-Line Antenna



5.3.3 Dimensions of the Antenna Elements

Figure 5-12. Dimensions of the Antenna Elements



5.3.4 VSWR and Emission Characteristics

Figure 5-13. VSWR Characteristic

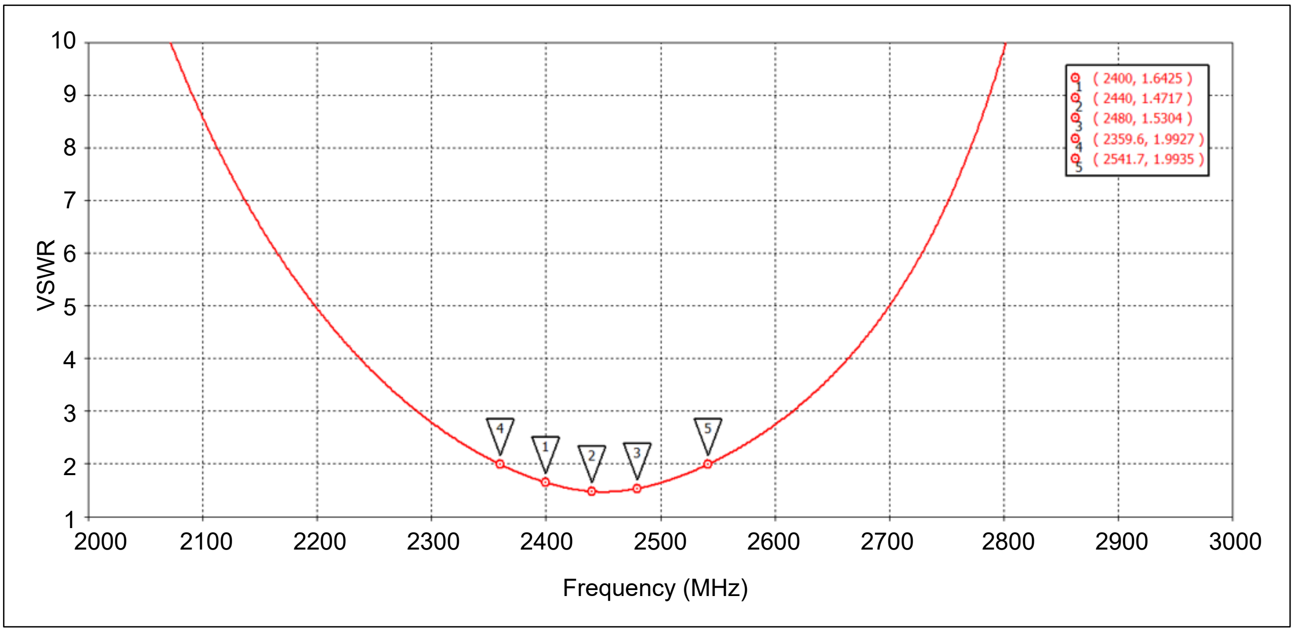
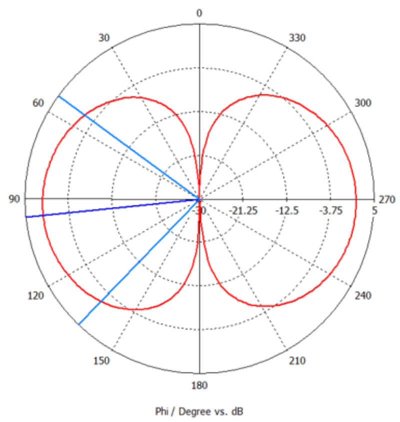


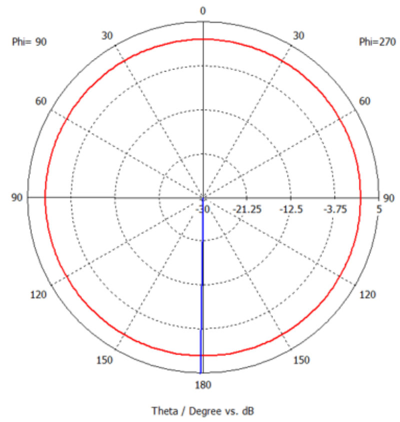
Figure 5-14. Emission Characteristics

(a) x-y plane (horizontally polarized wave)



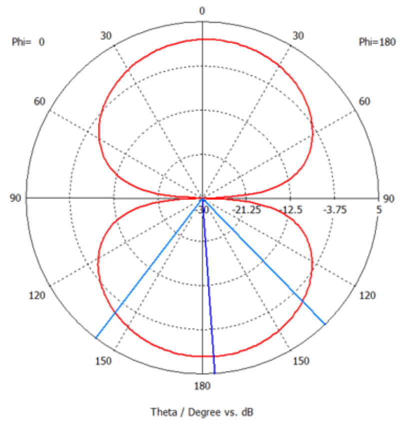
Average gain: -5.1 dBi
Maximum gain: 1.4 dBi

(b) y-z plane (vertically polarized wave)



Average gain: 1.4 dBi
Maximum gain: 1.5 dBi

(c) x-z plane (horizontally polarized wave)



Average gain: -5.4 dBi
Maximum gain: 1.5 dBi

6. EXAMPLE OF ADJUSTMENT FOR ANTENNA MATCHING

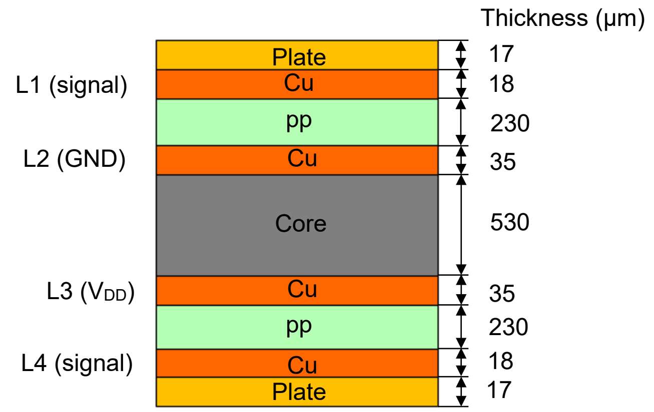
This chapter describes the concrete procedure for adjustment and optimization in forming an antenna on system board by using an example given in 5, EXAMPLES OF DESIGNING SMALL PATTERN ANTENNAS.c

Note that the system board is assumed to be deigned under the conditions listed below.

- Layer configuration of the board: 4 layers, total thickness of 1.2 mm (refer to figure 6-1)
- Board material: FR4 (dielectric constant εr: 4.3, dielectric loss tangent: 0.025)
- Board dimensions: 50 × 50 mm

An electromagnetic field simulator is used for the descriptions in this section. The procedures are the same for an actual antenna formed on the board for a system.

Figure 6-1. Layer Configuration of the Board Used in Adjustment for Matching



6.1 Modeling of an Antenna (or Making a Prototype) at the Corner of the Board

Model (or make a prototype) of an antenna on a board with reference to 5.3.3, Dimensions of the Antenna Elements. The board to be used in this section is thinner than 1.6 mm, which was the thickness in 5.3, Horizontal Meandering-Line Antenna (Simulated). Accordingly, take into account the electrical length of the meandering section in the direction of the thickness of the board being shorter, so make the elements longer.

Figure 6-2. Board Dimensions and Location of the Antenna (Unit: mm)

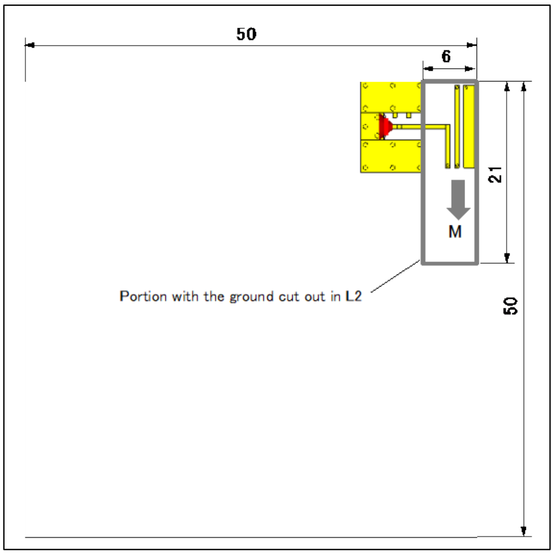
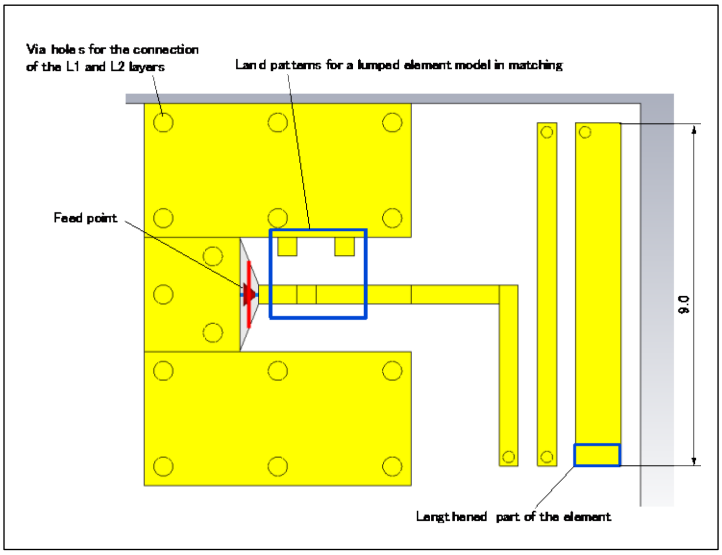
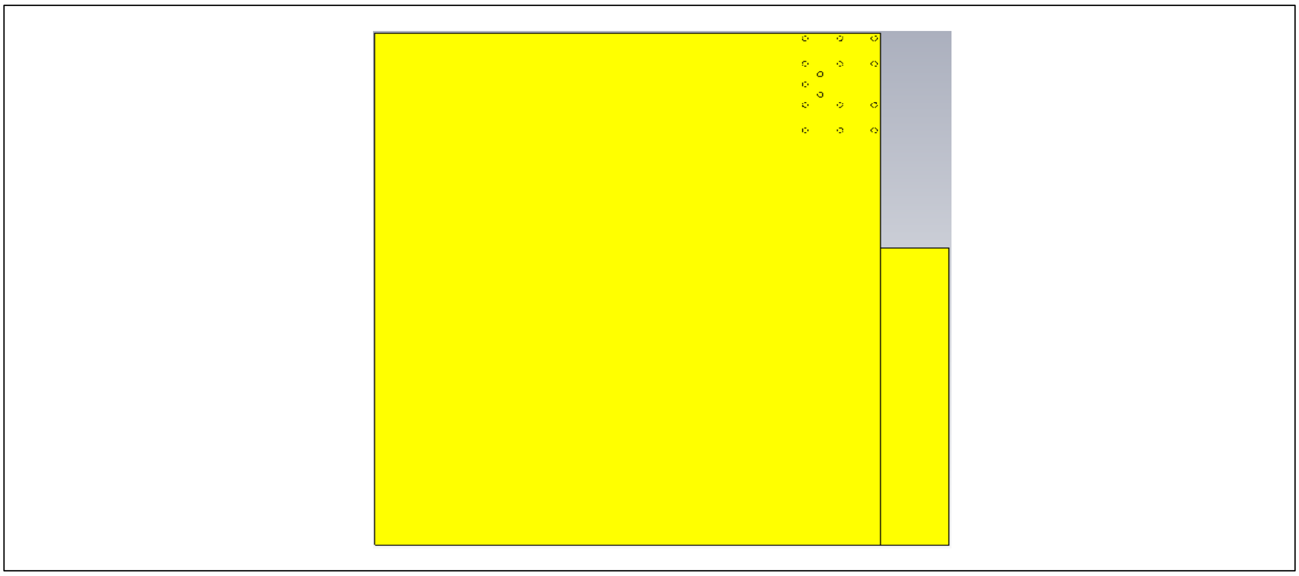


Figure 6-3. Enlarged View of the Antenna in Figure 6-2 (Unit: mm)



The system board to be used in this section is assumed to be larger than the size in 5.3 and to have the antenna at its corner as shown in figure 6-2.

Figure 6-4. L2 Ground Layer



Take into account the layer where the image effect of the antenna is formed. In this example, layers L1 and L2 are connected by using multiple via holes as shown in figure 6-3 and the image antenna is formed in the L2 layer.

Cut out the copper foil from L2 to L4 under the area where the lower part of the antenna is formed. Placing the antenna close to the ground in the M direction shown in figure 6-2 leads to poorer characteristics. For this reason, delete as much of the L2 ground as possible from this region.

In addition, use a solid ground for L2 except for the portion with the ground cut out shown in figure 6-2. The ground being divided into parts due to cuts as shown in figure 6-5, the image effect described in 1.2, Monopole Antenna cannot be formed, which also leads to poorer characteristics.

Figure 6-5. Ground Divided into Parts

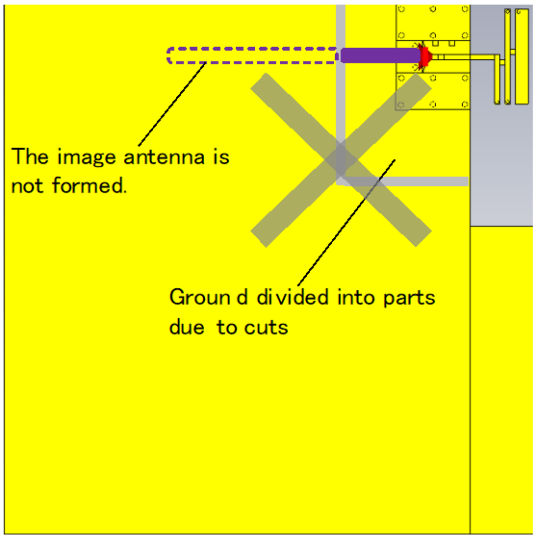
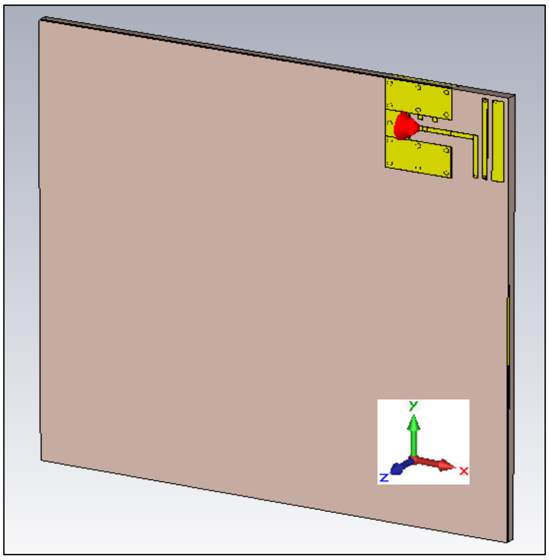


Figure 6-6 shows general views of the completed board.

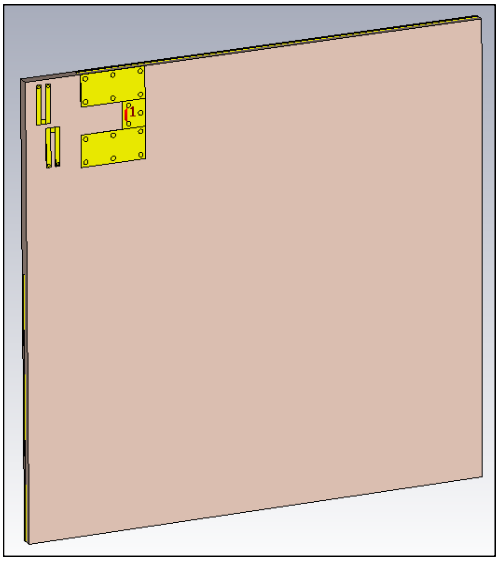
For an actual design, lands for components, patterns for signals and power supplies, and so on are arranged in layers L1, L3, and L4. Since these do not greatly affect the antenna characteristics, they are omitted here.

Figure 6-6. General View of the Board

(a) L1 layer



(b) L4 layer



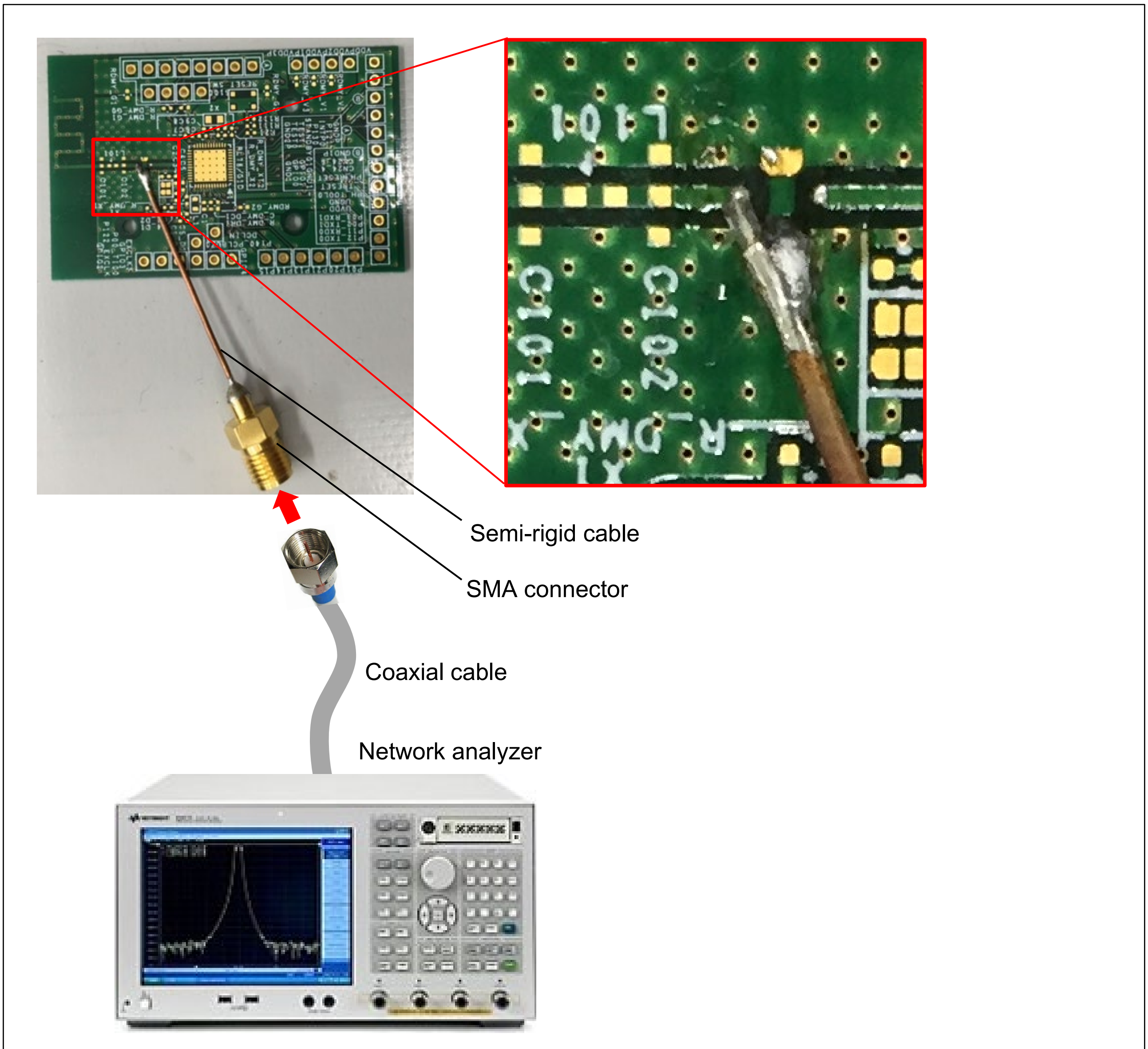
6.1.1 Attaching a Semi-Rigid Cable and Connection to a Network Analyzer (in Making a Prototype Board)

After the prototype board has been made, solder a semi-rigid cable with an SMA connector to the antenna as shown in figure 6-7.

Solder the center conductor of the cable to the feed point of the antenna and the outer conductor to the ground. If the ground is covered with resist in L1, scrape it off with a cutter, etc., before soldering the cable.

After that, connect the SMA connector to a network analyzer.

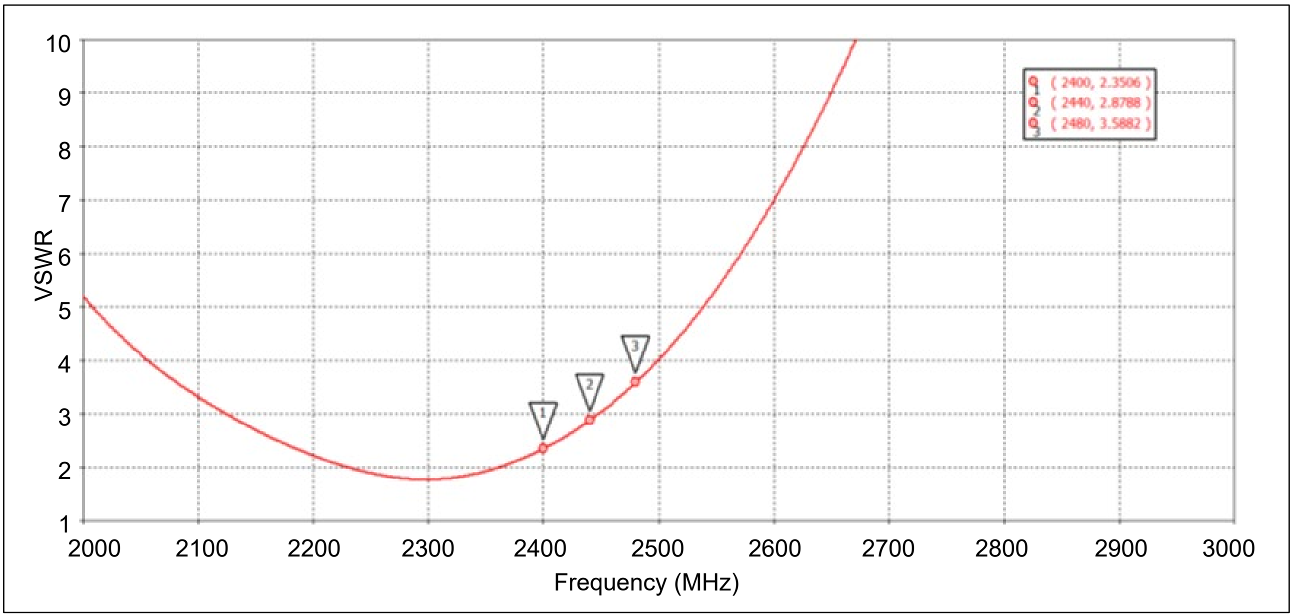
Figure 6-7. Connection between the Board and a Network Analyzer



6.1.2 Checking VSWR, Adjusting the Resonance Frequency, and Checking Emission Characteristics

The result of checking the VSWR is given in figure 6-8. Compared with the result obtained by the electromagnetic field simulator shown in 5.3.4, the resonance frequency is lowered to about 2300 GHz and the VSWR characteristic over the range of bandwidth from 2400 to 2480 MHz is deteriorated. We can consider this to be because of the capacitive hat at the top of the antenna elements, that is, expansion of the ground increases the capacitance and lowers the resonance frequency.

Figure 6-8. Result of Checking VSWR

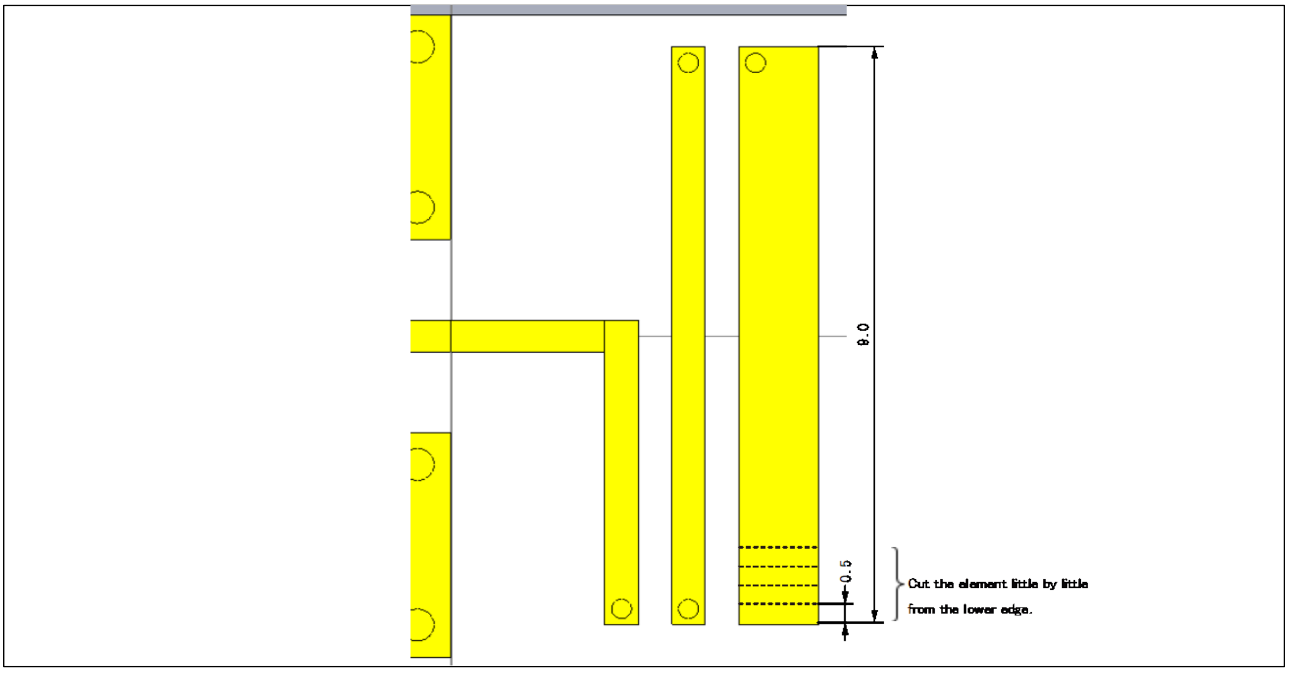


In the case above, cut the given antenna element to raise the resonance frequency.

Figure 6-9 shows an example of cutting for an electromagnetic field simulator.

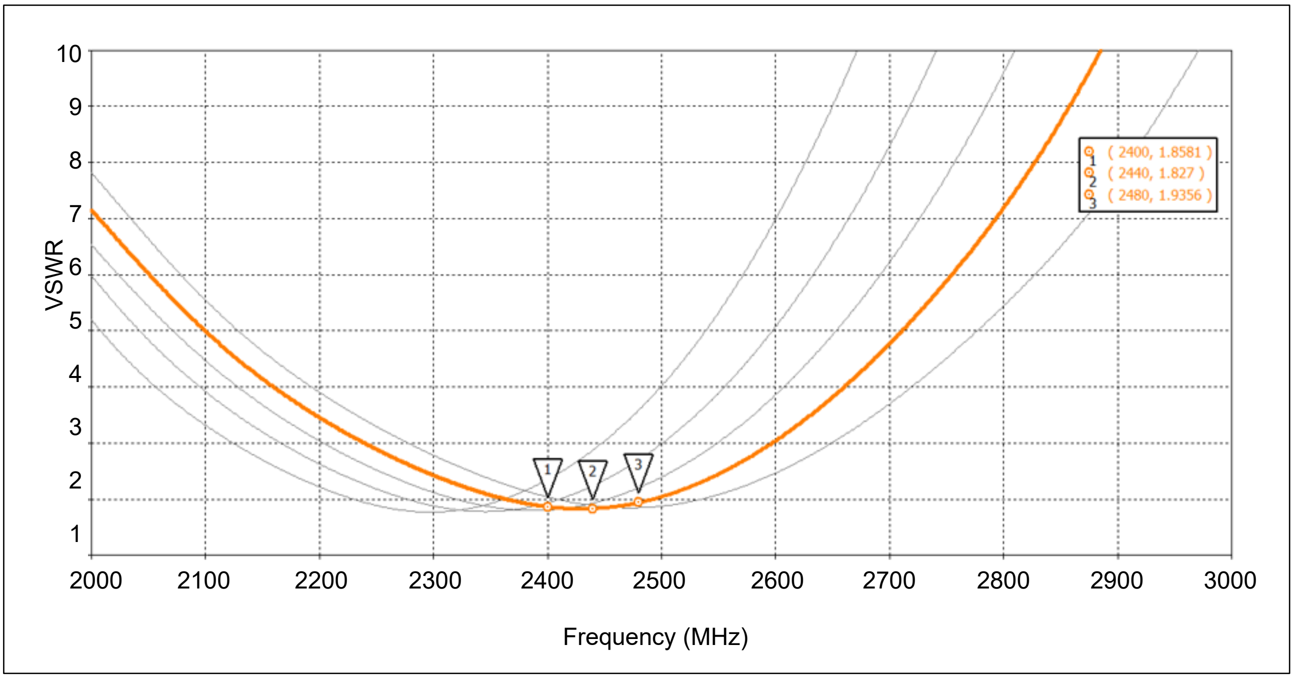
For a prototype board, use a stereomicroscope to cut the pattern little by little with a design knife or cutter and check the VSWR by using the network analyzer after each cut.

Figure 6-9. Cutting the Element (Unit: mm)



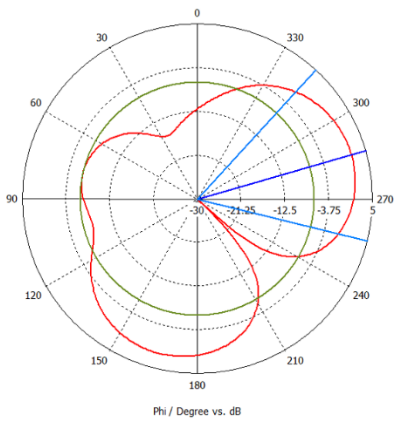
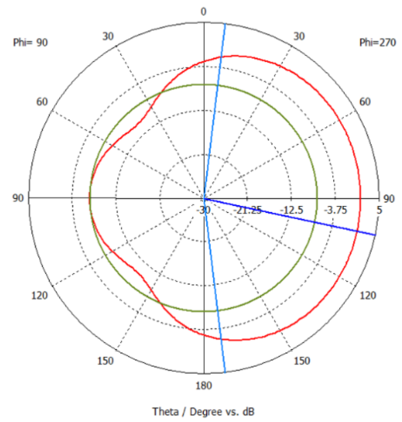
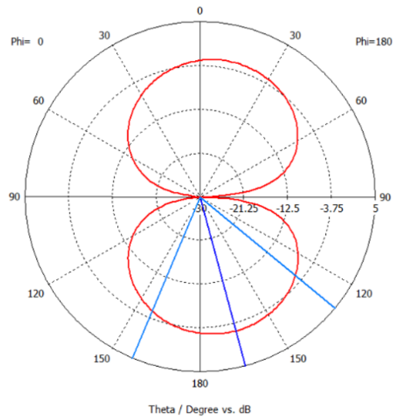
In the above evaluation, the element was shortened by 0.5 mm each time. Changes in the VSWR with the length by which the element was cut are shown in figure 6-10.

Figure 6-10. VSWRs Each Time the Element was Cut



Cutting the element by about 1.5 mm brings the bandwidth into the range from 2400 to 2480 MHz. Figure 6-11 shows the emission characteristics in this case.

Figure 6-11. Emission Characteristics after Cutting the Element

(a) x-y plane (horizontally polarized wave)	(b) y-z plane (vertically polarized wave)	(c) x-z plane (horizontally polarized wave)
 Average gain: -5.5 dBi Maximum gain: 2.0 dBi	 Average gain: -3.7 dBi Maximum gain: 1.3 dBi	 Average gain: -10.3 dBi Maximum gain: -2.3 dBi

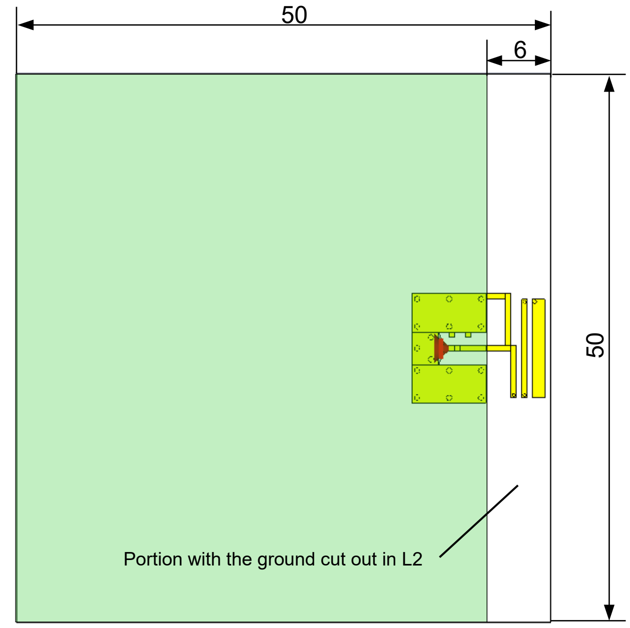
Compared with the emission characteristics shown in figure 5-14, there seems to be changes in the emission shape and some deterioration of the average gains in the above figure.

Conditions such as the size of the ground and the location of the antenna affect the antenna characteristics, so whether the required gain in the intended direction is being obtained or not needs to be taken into account in design.

6.2 Modeling of an Antenna (or Making a Prototype) on the Edge at the Center of the Board

In the same way as described in 6.1, model (or make a prototype) of an antenna on a board. Here, place the antenna on the edge at the center of the board as shown in figure 6-12.

Figure 6-12. Board Dimensions and Location of the Antenna (Unit: mm)



In the same way as described in 6.1, cut out the copper foil from L2 to L4 under the area where the lower part of the antenna is formed. In addition, connect layers L1 and L2 by using multiple via holes to form the image antenna in the L2 layer.

Figure 6-13. L2 Ground Layer

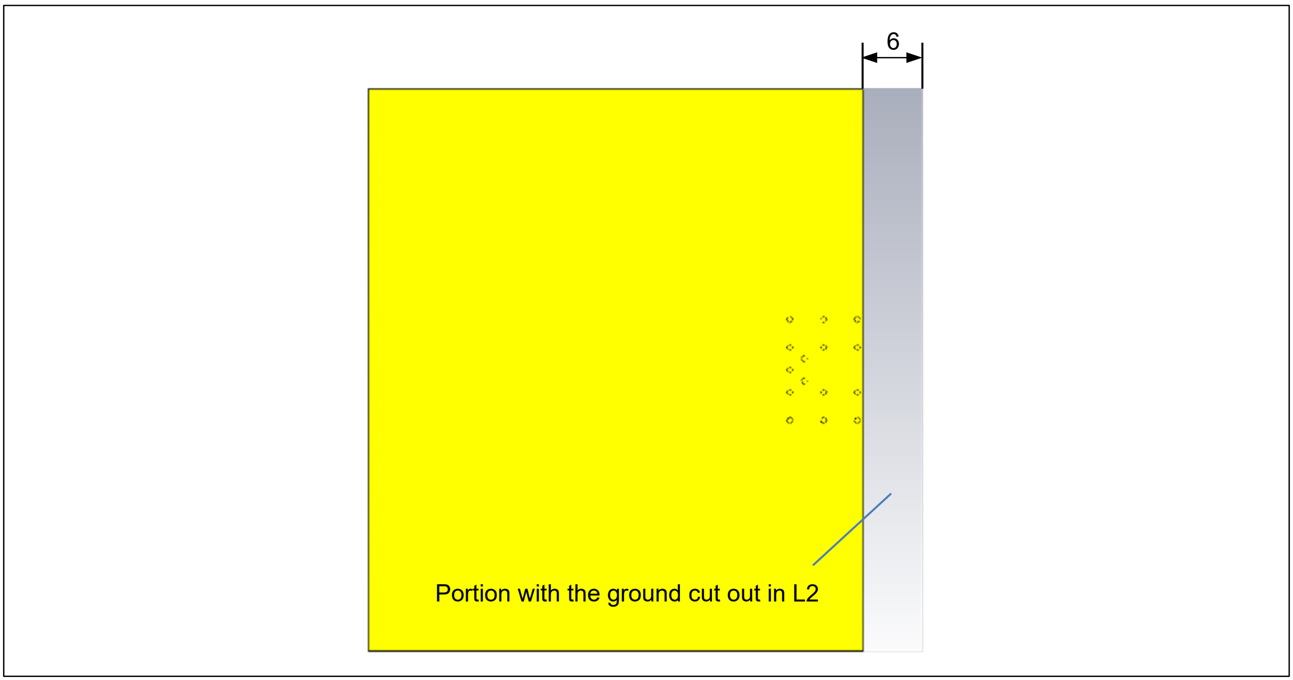
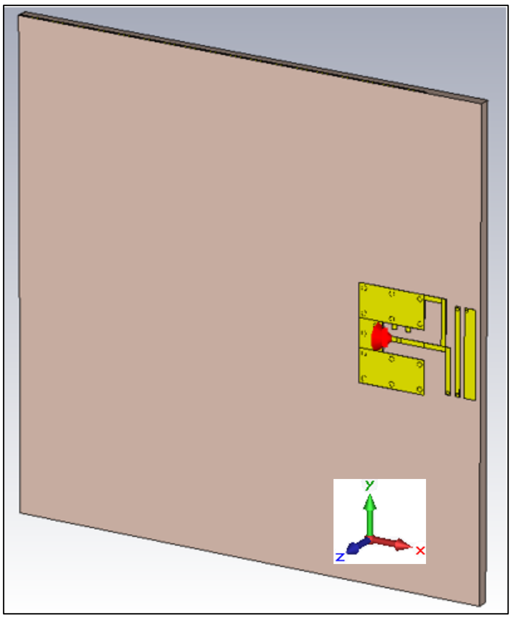
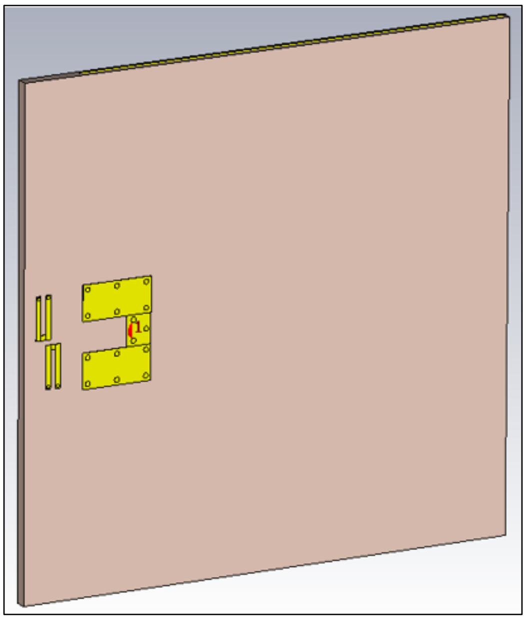


Figure 6-14. General View of the Board

(a) L1 layer



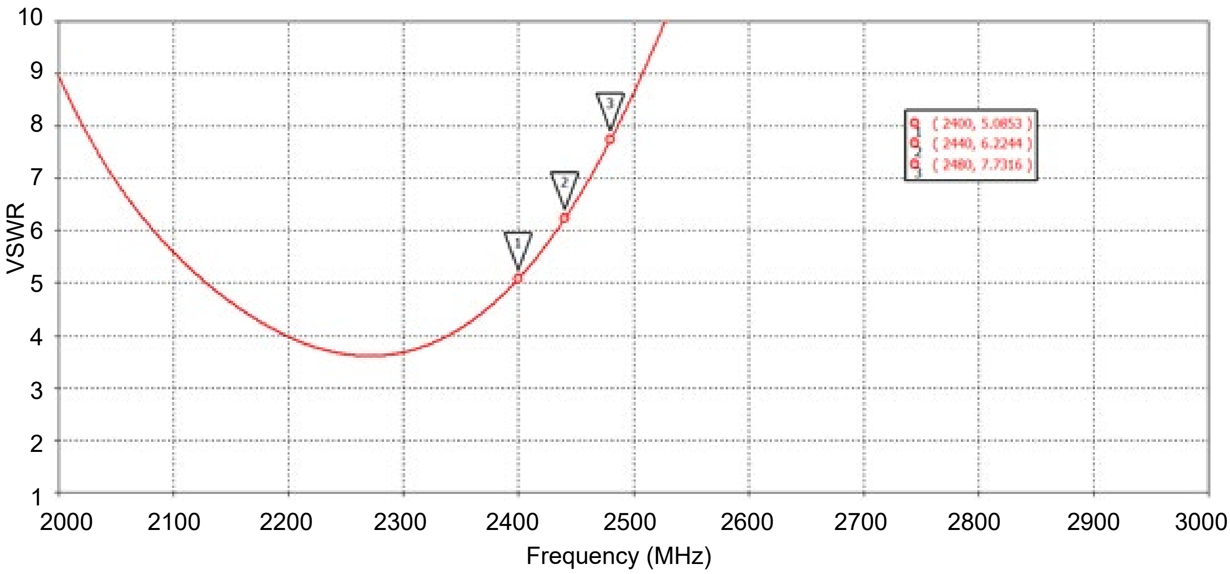
(b) L4 layer



6.2.1 Checking VSWR and Adjusting the Resonance Frequency

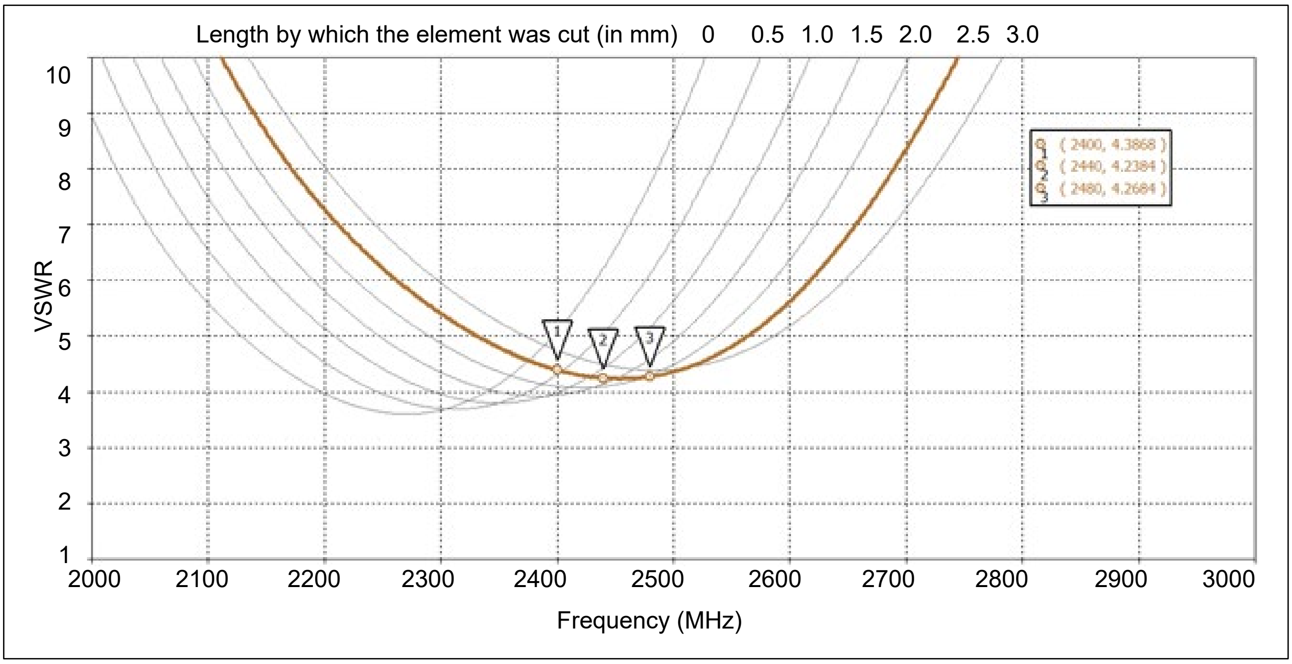
The result of checking the VSWR is given in figure 6-15. In the same way as shown in figure 6-8, the resonance frequency is lowered and the VSWR characteristic over the range of bandwidth from 2400 to 2480 MHz is deteriorated.

Figure 6-15. Result of Checking VSWR



In the case above, cut the given antenna element in the same way as described in figure 6.9 to raise the resonance frequency. Changes in the VSWR with the length by which the element was cut are shown in figure 6-16.

Figure 6-16 VSWRs Each Time the Element was Cut



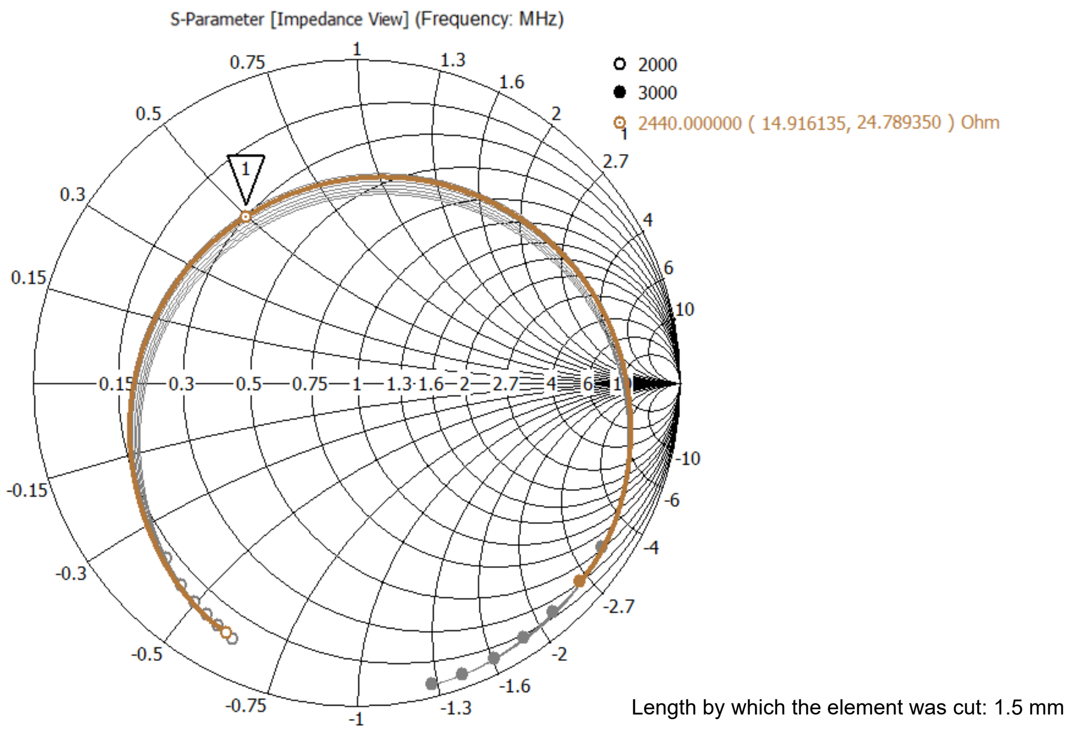
Cutting the element by about 2.5 mm raises the resonance frequency to the range approximately from 2400 to 2480 MHz, but the target condition VSWR ≤ 2 is not satisfied.

6.2.2 Measurement of Impedance and Matching by Using a Lumped Constant

If there seems to be some deterioration of the VSWR when the resonance frequency is at its peak as shown in figure 6-16, we can consider this to be because the antenna impedance diverges from 50 Ω in most cases.

In such cases, Smith charts are used to confirm the cause and proceed with matching. Figure 6-17 shows the Smith chart obtained by cutting the element in 6.2.1.

Figure 6-17. Smith Chart after Cutting the Element



Impedance at 2440 MHz can be calculated from the formula, Z = R + jX, where R ≈ 15 Ω and X ≈ 25 Ω in this measurement.

Place the value for Z obtained from the formula above at the center of the Smith chart in matching.

In this case, the Smith-Chart software tool can be used according to the following procedure.

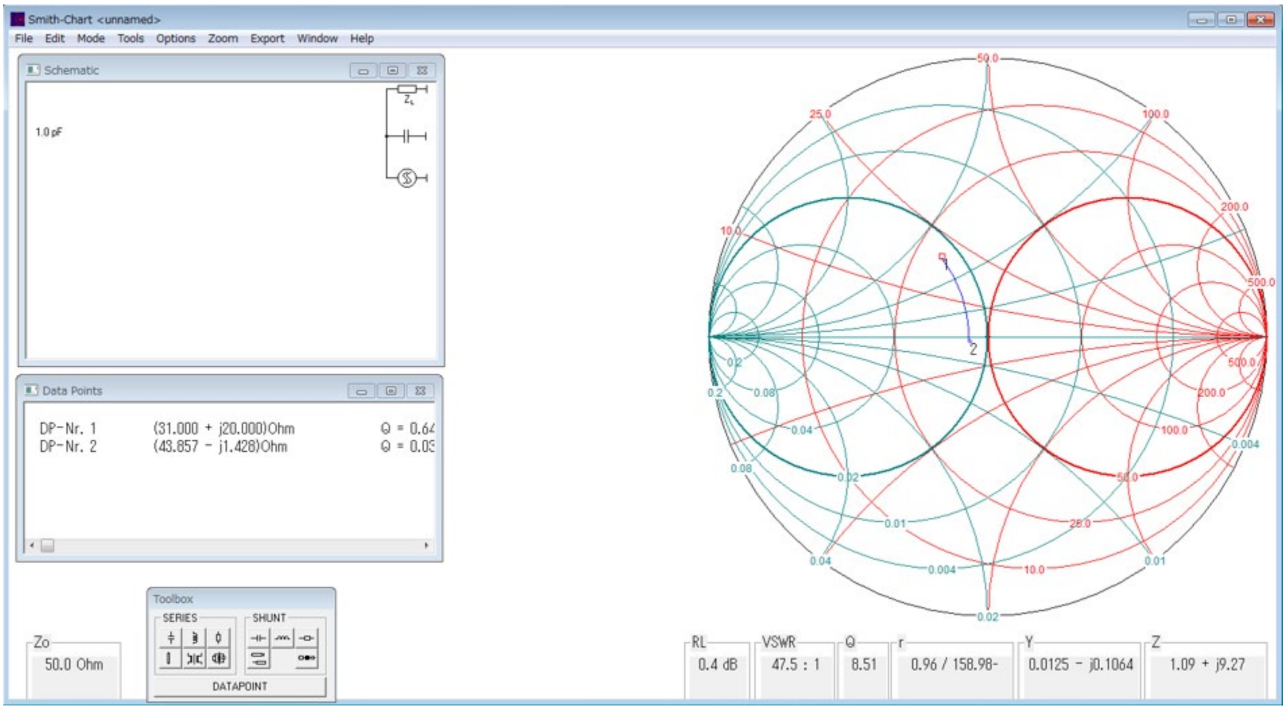
(1) Enter 2440 MHz and the values of R and X shown above in [Data Points] of the [Toolbox].

(2) Select a capacitor from [SHUNT] of the [Toolbox] and then move along the tracks.

(3) Check and use the circuit topology and matching constant in [Schematic].

The matching constant obtained from figure 6-17 through the Smith-Chart is given in figure 6-18. This result indicates that the adjustment for matching can be made by inserting a 2.0-pF capacitor between the antenna and ground.

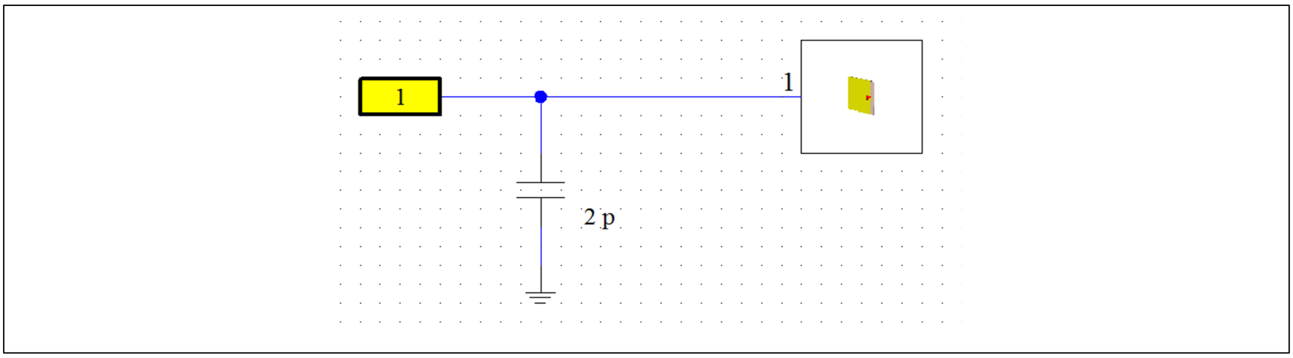
Figure 6-18. Obtaining the Matching Constant from a Smith-Chart



Input the lumped constant obtained from figure 6-18 to the electromagnetic field simulator as shown in figure 6-19.

For a prototype board, solder the component to the land pattern for a lumped element model in matching shown in figure 6-3.

Figure 6-19. Input of the Lumped Constant to the Electromagnetic Field Simulator



The VSWR and Smith chart after matching by both cutting the element and inserting the 2.0-pF capacitor are shown in figures 6-20 and 6-21, respectively.

Figure 6-20. VSWR after Matching by Both Cutting the Element and Inserting the 2.0-pF Capacitor

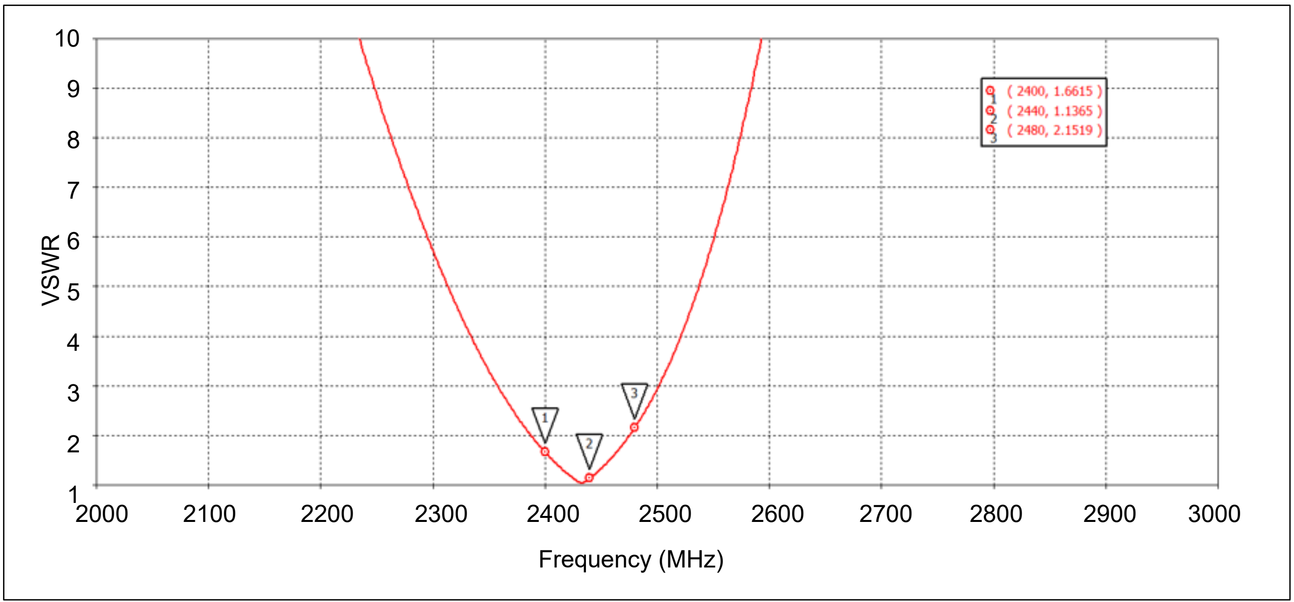
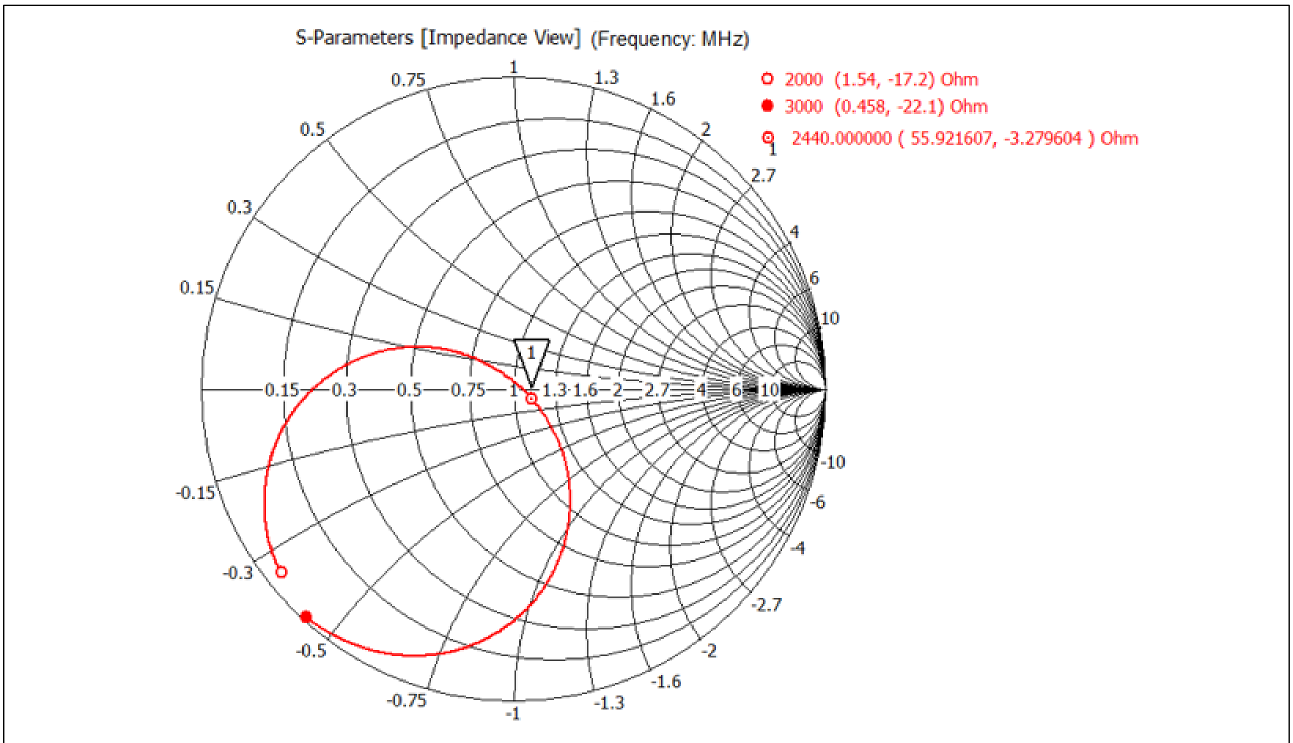


Figure 6-21. Smith Chart after Matching by Both Cutting the Element and Inserting the 2.0-pF Capacitor

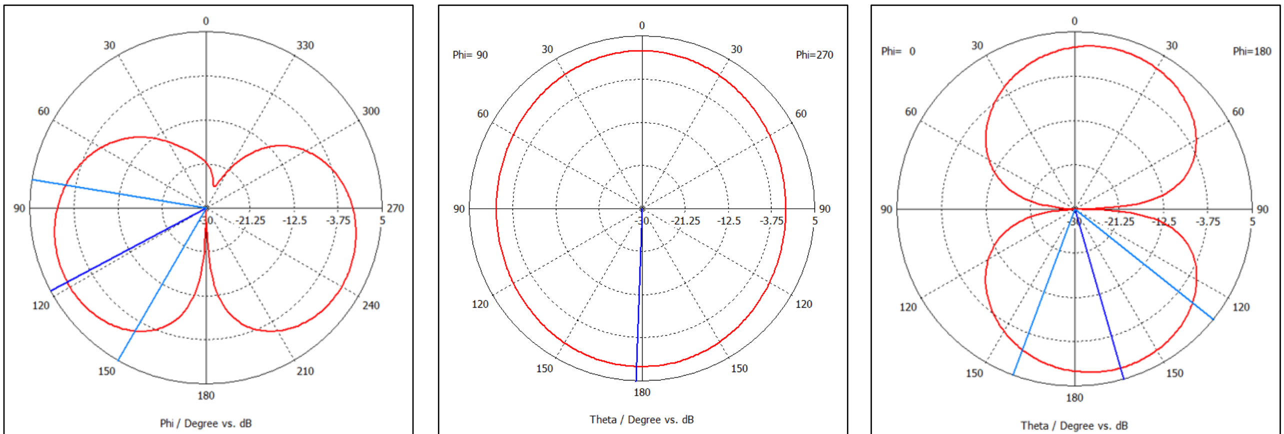


These figures indicate that the target condition VSWR ≤ 2 is almost satisfied and the value of Z is approximately 50 Ω.

The emission characteristics in this case are shown in figure 6-22.

Figure 6-22. Emission Characteristics after Matching by Both Cutting the Element and Inserting the 2.0-pF Capacitor

(a) x-y plane (horizontally polarized wave)	(b) y-z plane (vertically polarized wave)	(c) x-z plane (horizontally polarized wave)



Average gain: -9.6 dBi Maximum gain: 1.2 dBi	Average gain: -1.5 dBi Maximum gain: 2.0 dBi	Average gain: -7.7 dBi Maximum gain: -2.6 dBi

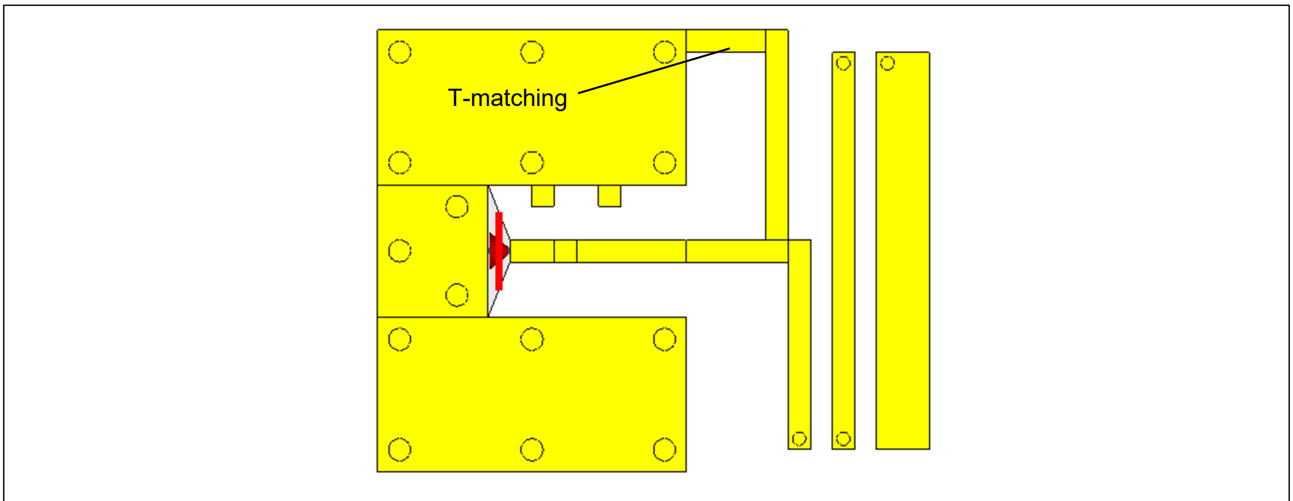
The figure indicates that the emission characteristics equivalent to those shown in figure 5-14 are obtained but the gains are reduced slightly.

6.2.3 Matching by Using a Distributed Constant

Adjustment for matching can equivalently be done by using a distributed constant instead of the method described in 6.2.2. This section explains an example of adjustment by adding a T-matching circuit. Note that employing this method requires simulation of the electromagnetic field before making a prototype and the evaluation of prototypes several times.

Figure 6-23 shows an example of adding a T-matching circuit.

Figure 6-23. Adding a T-Matching Circuit (Unit: mm)



Adding a T-matching circuit changes the electrical length of the antenna elements. For this reason, an element is again cut to adjust the resonance frequency characteristic.

The adjustment is made with the electromagnetic field simulator while changing the position where the T-matching circuit is added and the length by which the element is cut. Figure 6-25 shows the VSWR obtained under the most suitable conditions. Figure 6-26 shows the result of the Smith chart under the above conditions.

Figure 6-24. Matching by Both Cutting the Element and Adding a T-Matching Circuit

(a) Sweeping direction

(b) Most suitable conditions obtained from the sweeping results

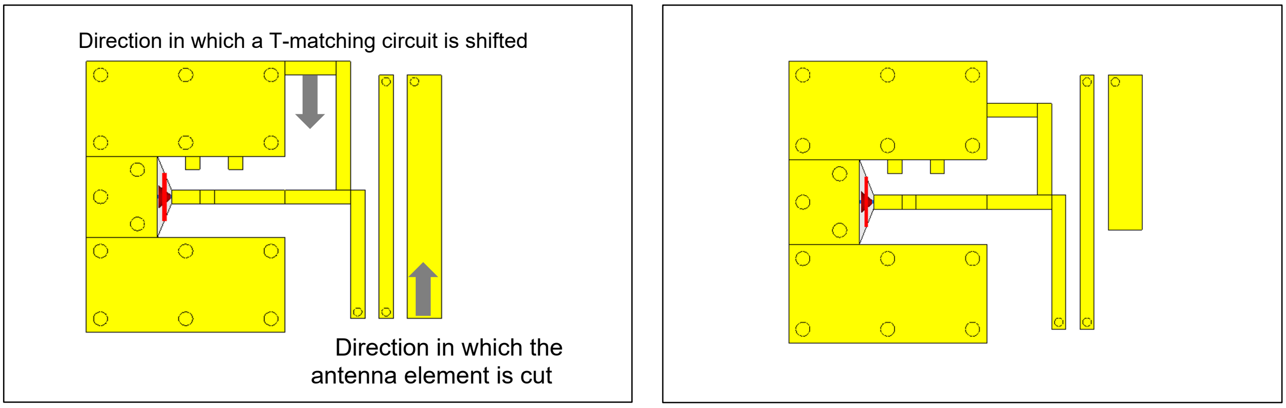


Figure 6-25. VSWR after Both Shifting a T-Matching Circuit by 1.5 mm and Cutting the Antenna Element by 3.5 mm

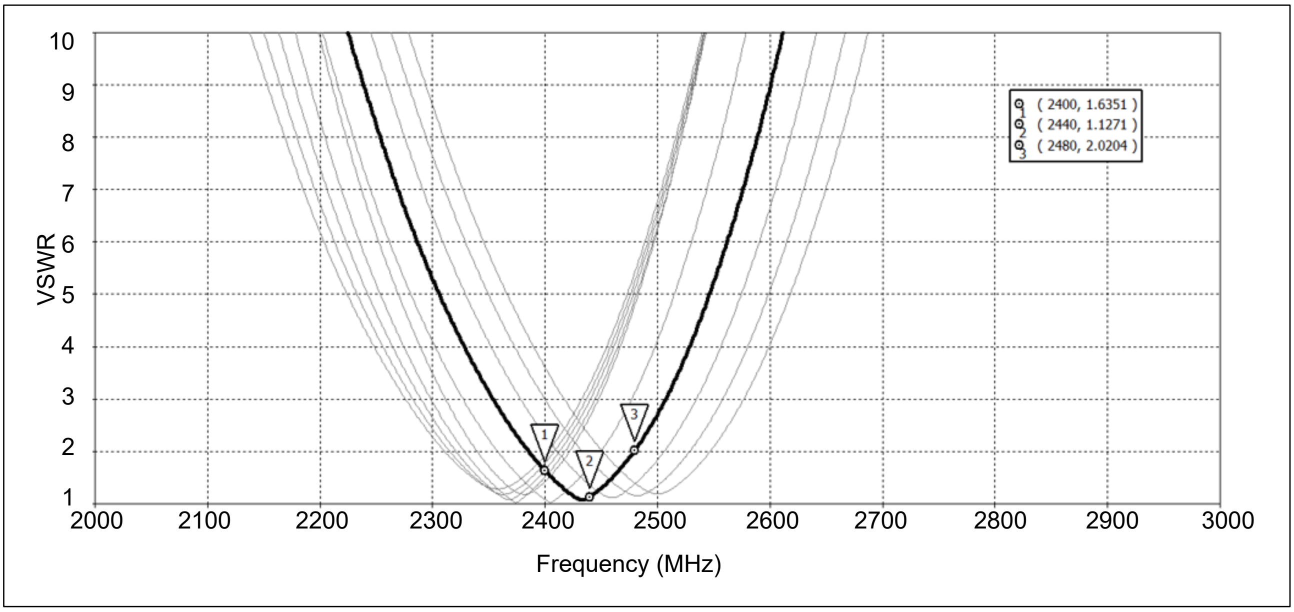


Figure 6-26. Smith Chart after Both Shifting a T-Matching Circuit by 1.5 mm and Cutting the Antenna Element by 3.5 mm

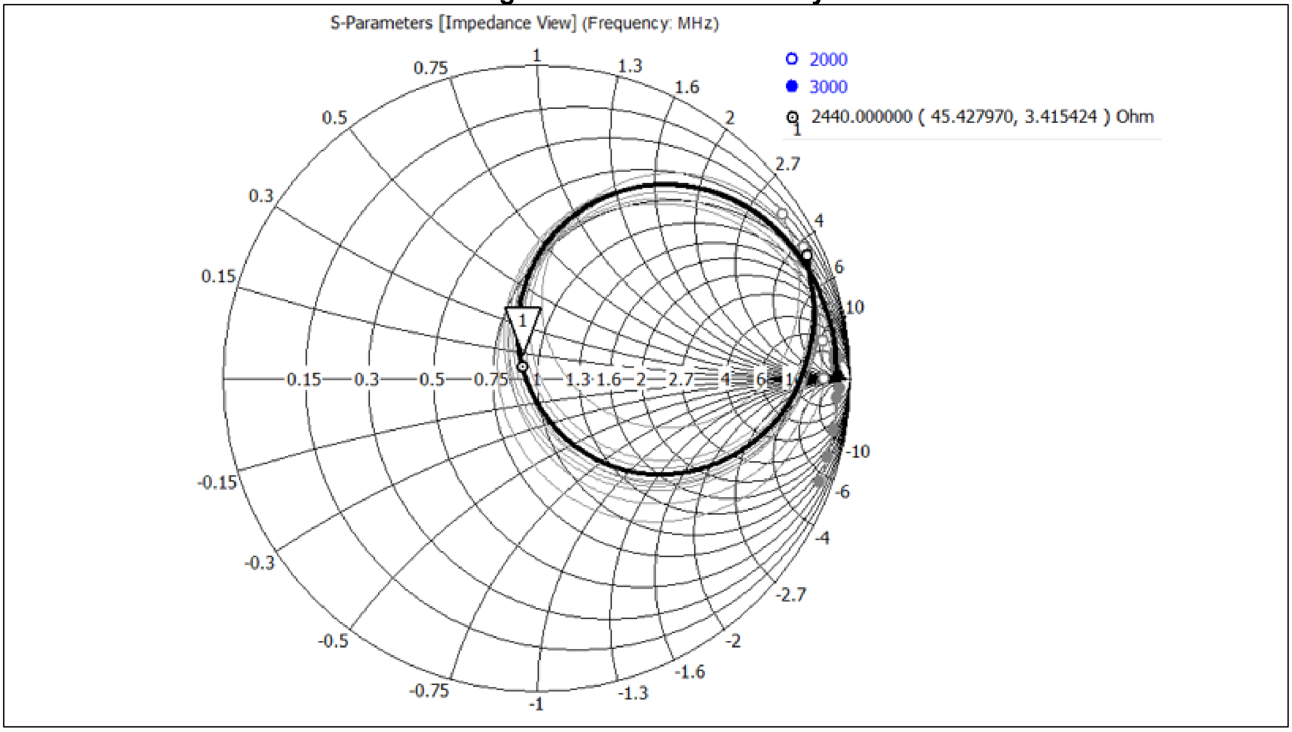
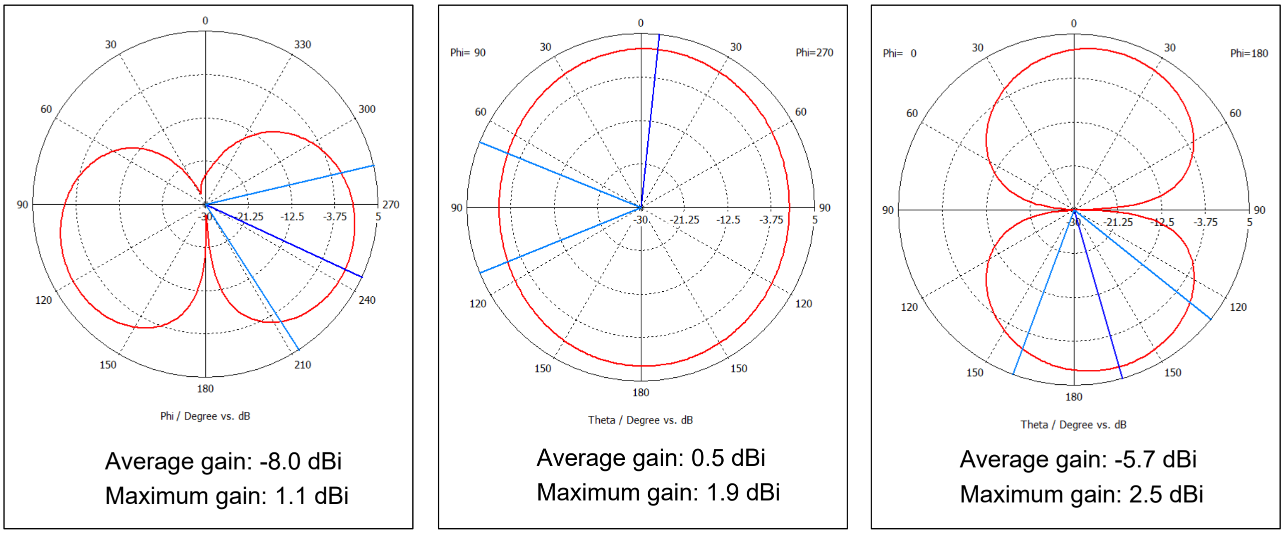


Figure 6-27 shows the emission characteristics.

Figure 6-27. Emission Characteristics after Matching by Both Cutting the Element and Adding a T-Matching Circuit

(a) x-y plane (horizontally polarized wave)	(b) y-z plane (vertically polarized wave)	(c) x-z plane (horizontally polarized wave)



The emission characteristics equivalent to those shown in figure 5-14 are obtained.

The gains are also the almost same.

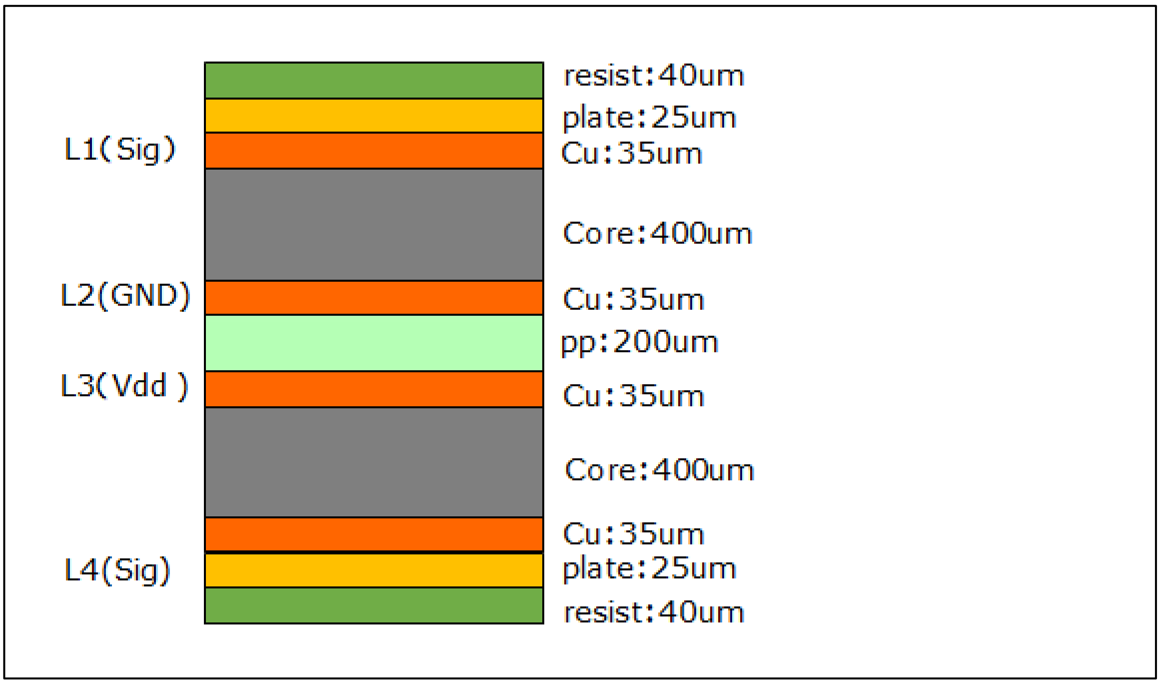
7. Prototype example of Antenna

This chapter describes the evaluation result of actually trial production with matching lumped constant.

7.1 Layer Configuration of the Prototype Board

Figure 7-1 shows the configration of the prototype board.

Figure 7-1. Layer Configuration of the Prototype Board



Base material : MCL-E-67(Hitachi Chemical)
Board total thickness : 1.3mm

7.2 Board dimensions of Antenna elements

Figure 7-2 to 7-4 shows the dimentions of Antenna elements of L1 to L4..

Figure 7-2. L1

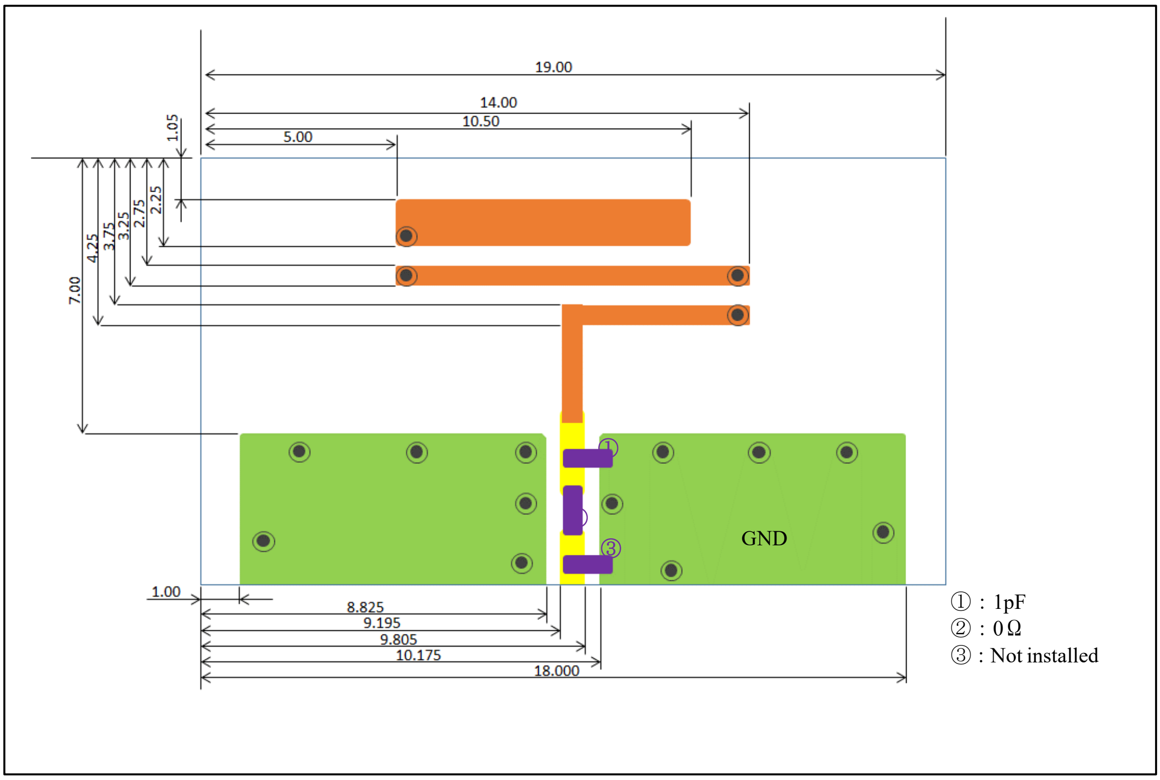


Figure 7-3. L2-L3

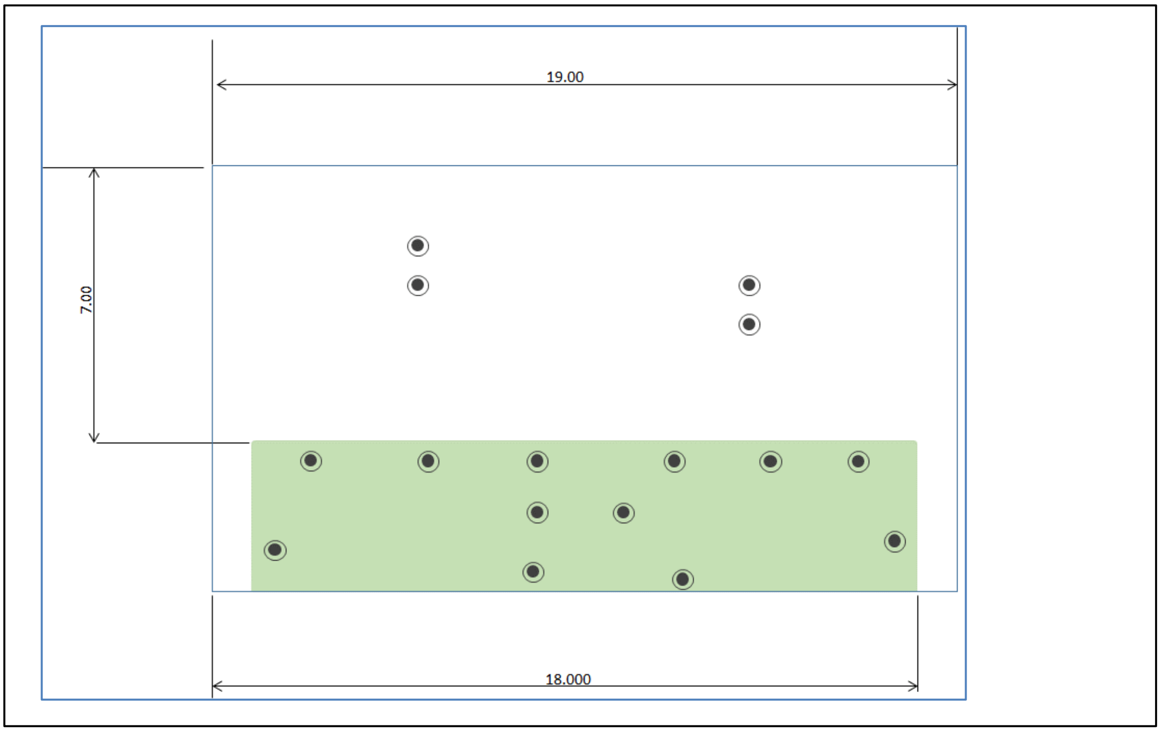
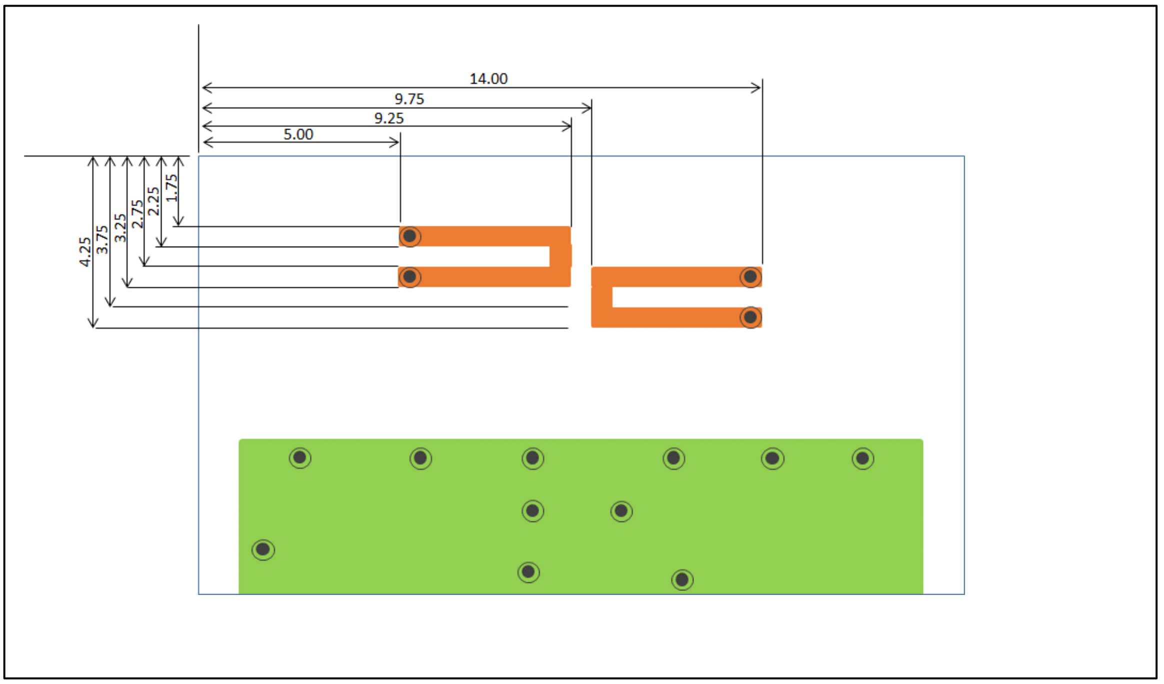
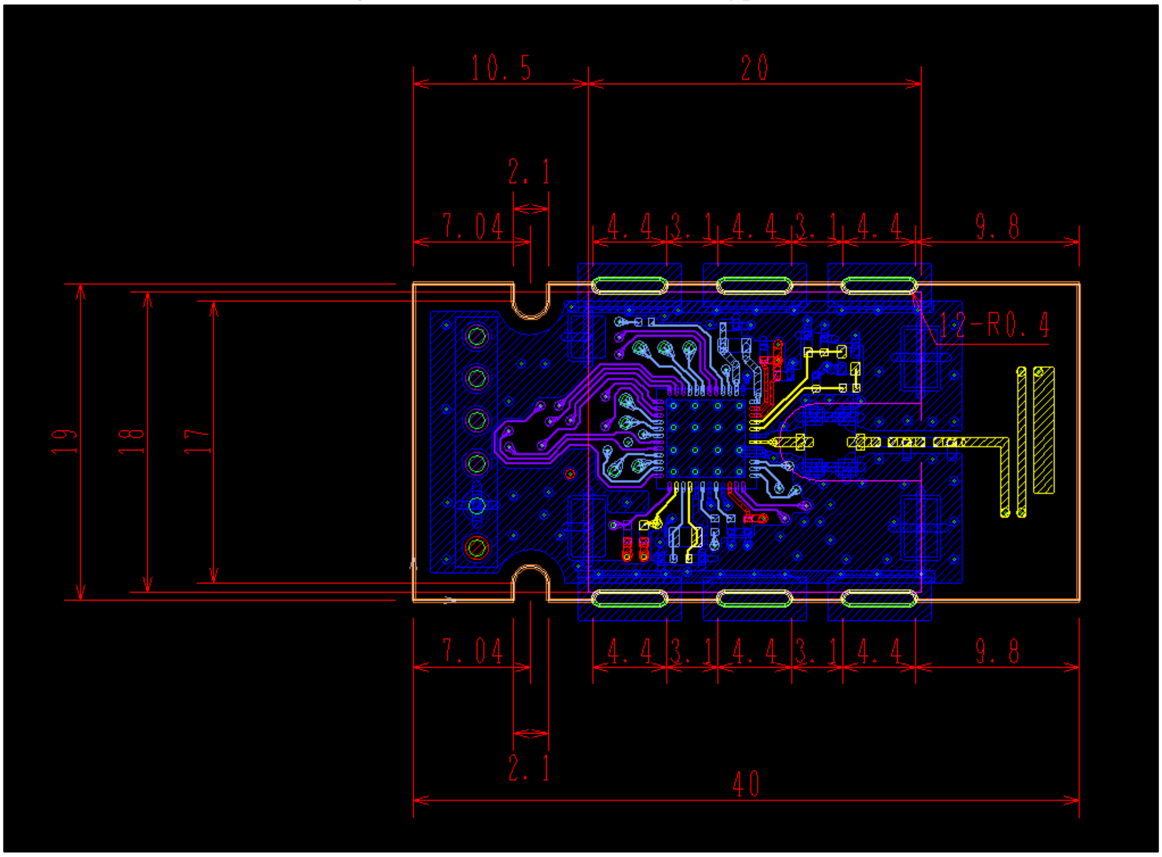


Figure 7-4. L4



7.3 Dimensions of Prototype Board

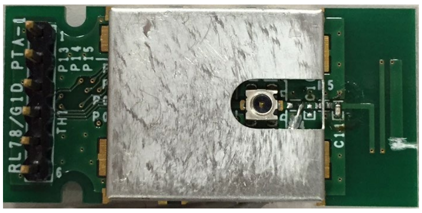
Figure 7-5. Dimension of Prototype Board



7.4 Photos of Prototype Board

Figure 7-6 shows the photos of prototype board.

Figure 7-6. Photos of Prototype Board

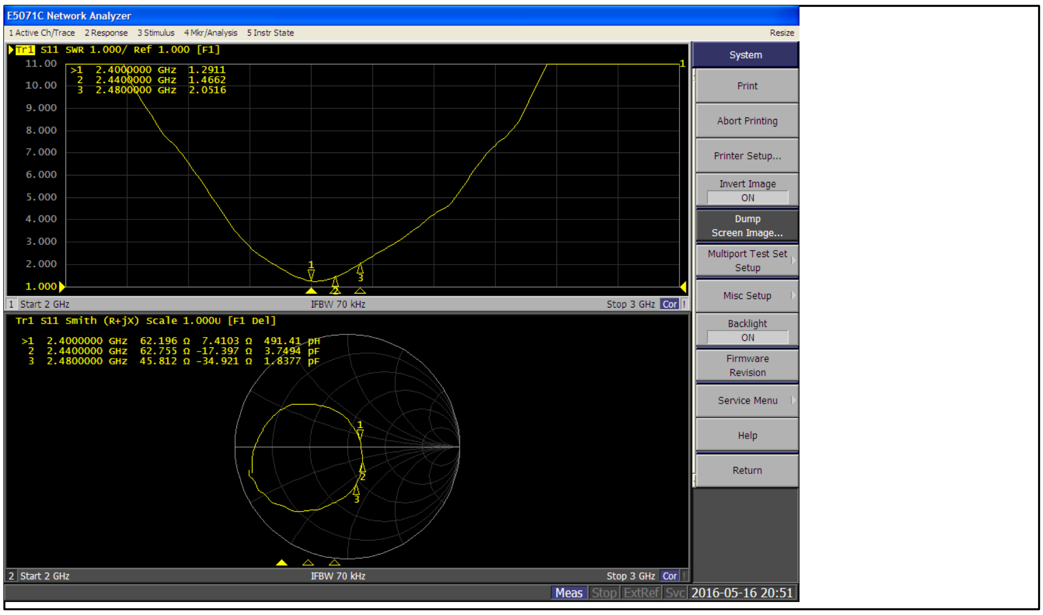


7.5 Evaluation Result of Prototype Board

7.5.1 VSWR

Figure 7-7 shows the VSWR of prototype board.

Figure 7-7. VSWR and Smith Chart

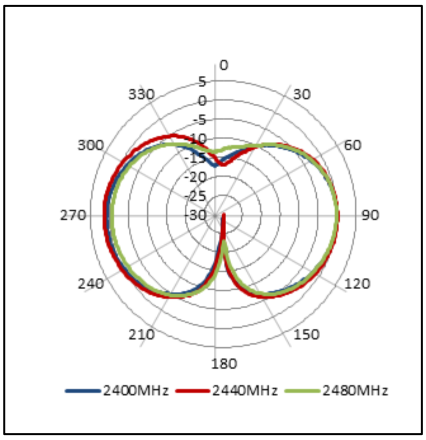


7.5.2 Radiation characteristics

Figure 7-8 shows the radiation of prototype board.

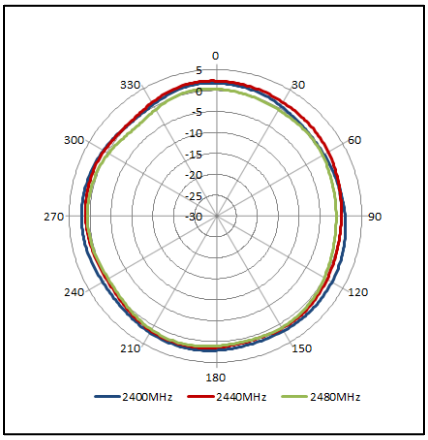
Figure 7-8. Radiation Characteristics

(a) x-y plane (horizontally polarized wave)



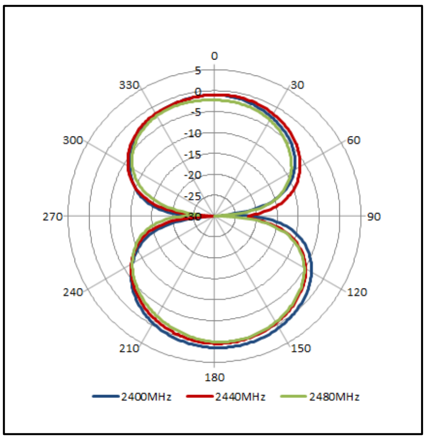
Average gain: -2.5 dBi
Max gain : 1.4 dBi

(b) y-z plane (vertically polarized wave)

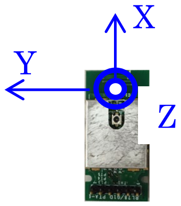


Average gain: 1.1 dBi
Max gain : 2.4 dBi

(c) x-z plane (horizontally polarized wave)



Average gain: -3.1 dBi
Max gain : 0.6 dBi



8. SUMMARY

Points to note in antenna design are summarized below.

8.1 Confirming the Environment for the Antenna Design

Prepare the following:

• A network analyzer (measurement environment for the VSWR and the Smith charts for S11)

• A six-surface anechoic chamber (measurement environment for the emission characteristics)

• An electromagnetic field simulator (for verification before making a prototype) [Note 1]

Note 1. This is not indispensable, but using it can improve the efficiency of the design process.

8.2 Clarifying the Antenna Specifications

Consider the specifications of the system among those listed below to select the most suitable antenna.

Directional characteristic, wave polarization characteristic, area and volume for forming the antenna, and communications range

8.3 Securing the Size of the Ground

Linear antennas (such as inverted-L, inverted-F, and meandering-line antennas) based on a monopole antenna and chip antennas require a ground of sufficient size relative to the wavelength and free of cuts in order to obtain the image effect.

Also include a solid ground in the layer configuration of the system board, taking forming of the image antenna into account.

8.4 Electromagnetic Field Simulation or Trial Manufacture by Using a Design Example

Use an example of the design of a small pattern antenna to model an antenna with the electromagnetic field simulator or to manufacture a system board with the antenna mounted for the purpose of a trial.

Conditions such as the size of the ground of the system board, the position where the antenna is mounted, the housing and antenna being close to each other, and metal and the antenna being close to each other may affect the antenna characteristics. For this reason, give sufficient consideration to determining the housing material and to the allocation of components near the antenna.

8.5 Adjustment for Matching and Parameters

Adjustment for matching will be required in most cases after an antenna is mounted on a system board.

Check the VSWR and S11 from the Smith chart, and then proceed with matching to satisfy the condition VSWR < 2 or 3.

Matching can be obtained through various methods, such as adjusting the length of an antenna element or adding a lumped or distributed constant.

Note that matching should proceed with the system assembled and housed.

8.6 Emission Characteristics

Measure the emission characteristics after adjustment for matching. Check the maximum and average gains and the directions of emission, and confirm that the intended communications range is obtained.

The maximum gain is also required for an application in relation to the Radio Law.

9. TOOL INFORMATION (FOR REFERENCE)

Note that Renesas has not verified the operation of the tools listed below.

If you are using any of them, do so in accord with the regulations on the license and at your own responsibility.

9.1 Electromagnetic Field Simulator

Two usable products are listed below.

CST STUDIO SUITE (AET, INC.)

HFSS (ANSYS, Inc.)

9.2 Smith Chart

Smith (Bern University)

Revision History

Rev.	Date	Description	
		Page	Summary
1.00	Mar.04.16	—	First edition issued
1.01	Oct.17.16	39-43 24,30	Added Prototype evaluation result. Figure6-6, 6-14. Changed XYZ coordinate definition drawing.
1.02	Dec.25.17	—	Added Precautions.
1.03	Dec.26.19	—	Changed target device from the RL78/G1D to the Bluetooth Low Energy microcomputer (RL78/G1D, RX23W). Replaced the "General Precautions in the Handling of Products" and the "Notice" with the latest.
1.04	May.07.20	—	Added Target Device “RA4W1”
1.05	Mar.25.21	—	Added Target Device “RE01B”

General Precautions in the Handling of Microprocessing Unit and Microcontroller Unit Products

The following usage notes are applicable to all Microprocessing unit and Microcontroller unit products from Renesas. For detailed usage notes on the products covered by this document, refer to the relevant sections of the document as well as any technical updates that have been issued for the products.

1. Precaution against Electrostatic Discharge (ESD)
   A strong electrical field, when exposed to a CMOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop the generation of static electricity as much as possible, and quickly dissipate it when it occurs. Environmental control must be adequate. When it is dry, a humidifier should be used. This is recommended to avoid using insulators that can easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors must be grounded. The operator must also be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions must be taken for printed circuit boards with mounted semiconductor devices.
2. Processing at power-on
   The state of the product is undefined at the time when power is supplied. The states of internal circuits in the LSI are indeterminate and the states of register settings and pins are undefined at the time when power is supplied. In a finished product where the reset signal is applied to the external reset pin, the states of pins are not guaranteed from the time when power is supplied until the reset process is completed. In a similar way, the states of pins in a product that is reset by an on-chip power-on reset function are not guaranteed from the time when power is supplied until the power reaches the level at which resetting is specified.
3. Input of signal during power-off state
   Do not input signals or an I/O pull-up power supply while the device is powered off. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements. Follow the guideline for input signal during power-off state as described in your product documentation.
4. Handling of unused pins
   Handle unused pins in accordance with the directions given under handling of unused pins in the manual. The input pins of CMOS products are generally in the high-impedance state. In operation with an unused pin in the open-circuit state, extra electromagnetic noise is induced in the vicinity of the LSI, an associated shoot-through current flows internally, and malfunctions occur due to the false recognition of the pin state as an input signal become possible.
5. Clock signals
   After applying a reset, only release the reset line after the operating clock signal becomes stable. When switching the clock signal during program execution, wait until the target clock signal is stabilized. When the clock signal is generated with an external resonator or from an external oscillator during a reset, ensure that the reset line is only released after full stabilization of the clock signal. Additionally, when switching to a clock signal produced with an external resonator or by an external oscillator while program execution is in progress, wait until the target clock signal is stable.
6. Voltage application waveform at input pin
   Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (Max.) and V_{IH} (Min.) due to noise, for example, the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (Max.) and V_{IH} (Min.).
7. Prohibition of access to reserved addresses
   Access to reserved addresses is prohibited. The reserved addresses are provided for possible future expansion of functions. Do not access these addresses as the correct operation of the LSI is not guaranteed.
8. Differences between products
   Before changing from one product to another, for example to a product with a different part number, confirm that the change will not lead to problems. The characteristics of a microprocessing unit or microcontroller unit products in the same group but having a different part number might differ in terms of internal memory capacity, layout pattern, and other factors, which can affect the ranges of electrical characteristics, such as characteristic values, operating margins, immunity to noise, and amount of radiated noise. When changing to a product with a different part number, implement a system-evaluation test for the given product.

Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.
3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You shall be responsible for determining what licenses are required from any third parties, and obtaining such licenses for the lawful import, export, manufacture, sales, utilization, distribution or other disposal of any products incorporating Renesas Electronics products, if required.
5. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.
6. Renesas Electronics products are classified according to the following two quality grades: “Standard” and “High Quality”. The intended applications for each Renesas Electronics product depends on the product’s quality grade, as indicated below.
   "Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.
   "High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.
   Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user’s manual or other Renesas Electronics document.
7. No semiconductor product is absolutely secure. Notwithstanding any security measures or features that may be implemented in Renesas Electronics hardware or software products, Renesas Electronics shall have absolutely no liability arising out of any vulnerability or security breach, including but not limited to any unauthorized access to or use of a Renesas Electronics product or a system that uses a Renesas Electronics product. RENESAS ELECTRONICS DOES NOT WARRANT OR GUARANTEE THAT RENESAS ELECTRONICS PRODUCTS, OR ANY SYSTEMS CREATED USING RENESAS ELECTRONICS PRODUCTS WILL BE INVULNERABLE OR FREE FROM CORRUPTION, ATTACK, VIRUSES, INTERFERENCE, HACKING, DATA LOSS OR THEFT, OR OTHER SECURITY INTRUSION (“Vulnerability Issues”). RENESAS ELECTRONICS DISCLAIMS ANY AND ALL RESPONSIBILITY OR LIABILITY ARISING FROM OR RELATED TO ANY VULNERABILITY ISSUES. FURTHERMORE, TO THE EXTENT PERMITTED BY APPLICABLE LAW, RENESAS ELECTRONICS DISCLAIMS ANY AND ALL WARRANTIES, EXPRESS OR IMPLIED, WITH RESPECT TO THIS DOCUMENT AND ANY RELATED OR ACCOMPANYING SOFTWARE OR HARDWARE, INCLUDING BUT NOT LIMITED TO THE IMPLIED WARRANTIES OF MERCHANTABILITY, OR FITNESS FOR A PARTICULAR PURPOSE.
8. When using Renesas Electronics products, refer to the latest product information (data sheets, user’s manuals, application notes, “General Notes for Handling and Using Semiconductor Devices” in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.
9. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.
10. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
11. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.
12. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.
13. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
14. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.

(Note1) “Renesas Electronics” as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.

(Note2) “Renesas Electronics product(s)” means any product developed or manufactured by or for Renesas Electronics.

(Rev.5.0-1 October 2020)

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,
Koto-ku, Tokyo 135-0061, Japan
www.renesas.com

Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.

Contact information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit: www.renesas.com/contact/.