DRJC-11H05

Application note (3nd Edition)

Chip Antenna
— influencing factors of antenna properties —

MITSUBISHI MATERIALS CORPORATION
ELECTRONIC COMPONENTS DIVISION

Application note（3rd Edition）

Introduction

Since antenna properties of a built-in antenna generally depend on the conditions of the PCB on which it is mounted, proper PCB design and the arrangement of electronic components are indispensable for achieving the best antenna performance. The purpose of this document is to provide readers with PCB design tips and recommendations by showing the results of antenna properties under various conditions.

The antenna sample used throughout this report is based on Mitsubishi Material's chip antenna AM11DP-ST01 tuned at a frequency of 430MHz. It is assumed that results and recommendations throughout the contents of this report would also be applicable for other frequencies such as 315MHz, 868MHz, 915MHz and so on.

Contents

1. Fundamental Properties (AM11DP-ST01 at 430MHz)

Fig.1-1 shows the image of the standard sample board (dimensions of 86mm X 54mm), which is the same size as a credit card. The characteristics of AM11DP-ST01 tuned at 430MHz are presented in Fig.1-2 as a VSWR property and Fig.1-3 as a radiation property. This standard antenna sample has bandwidth of 16MHz at VSWR of 2.5 and an average antenna gain of about –11.72 dBd in YZ-plane vertical polarization. These properties are typical under the current conditions and not guaranteed for all conditions.

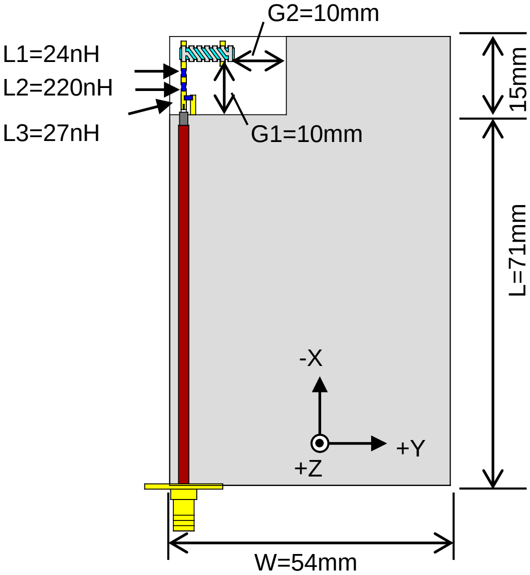


Fig.1-1. Dimensions of the standard antenna sample

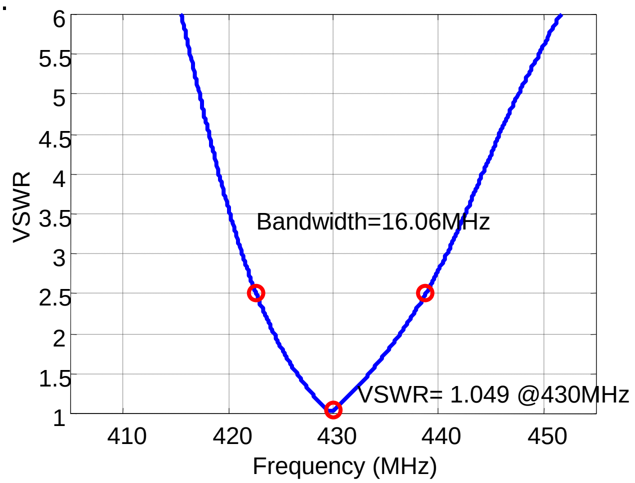
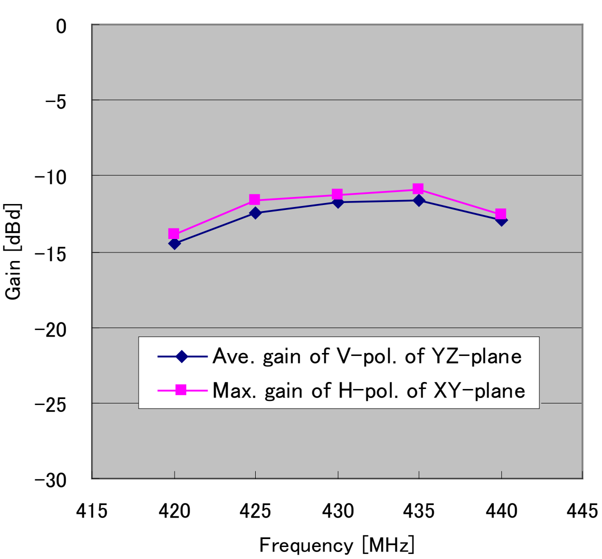


Fig.1-2. VSWR property of the standard antenna sample



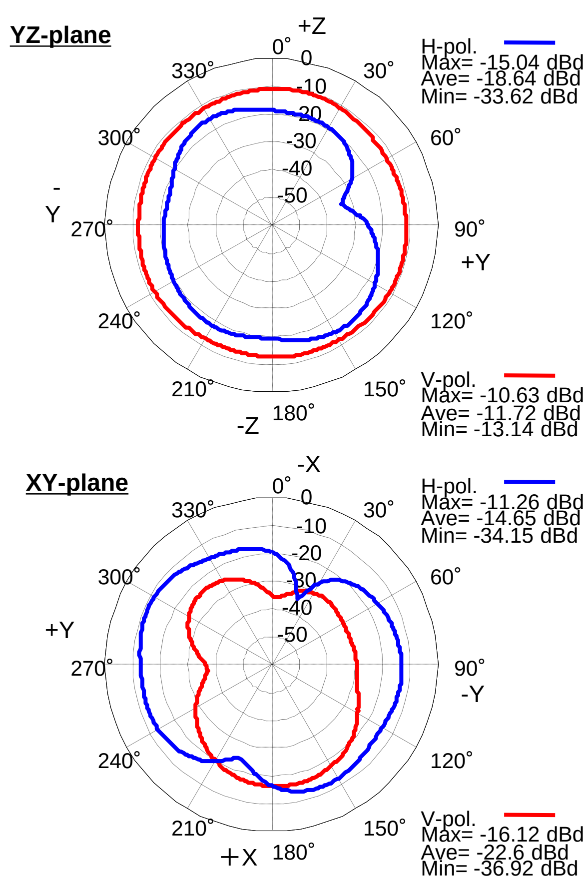
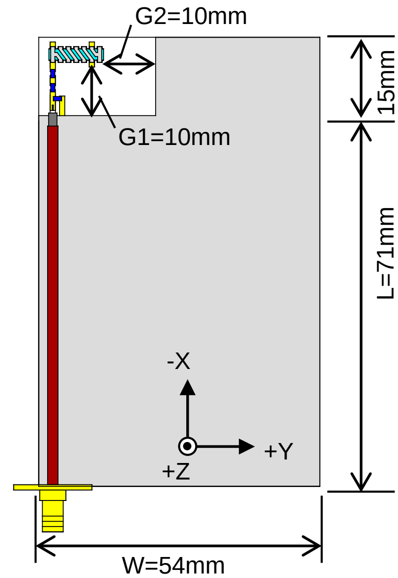


Fig.1-3. Radiation pattern of the standard antenna sample

2. Antenna properties and the distance between the antenna chip and the GND

This experiment investigated how the distance between antenna and GND influences the antenna performance.

- Both bandwidth and average antenna gain of V-polarization in YZ-plane tended to improve by increasing the of distance of G1 as shown in Fig.2-1 and Fig.2-2, respectively.
- When G1 is enlarged from 2.5mm to 15mm , bandwidth and average antenna gain were improved by 2.49MHz and 2.53dB, respectively.
- As shown in Fig.2-3 and Fig.2-4 it was found that distance G2 has similar effect on the bandwidth and gain properties. The improvements were 2.59MHz and 2.62dB, respectively.



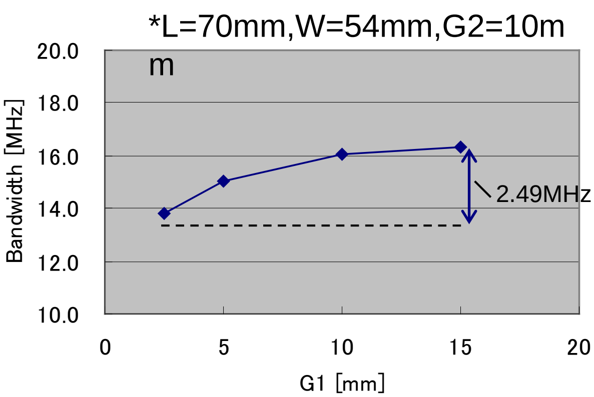


Fig.2-1. Bandwidth versus distance G1

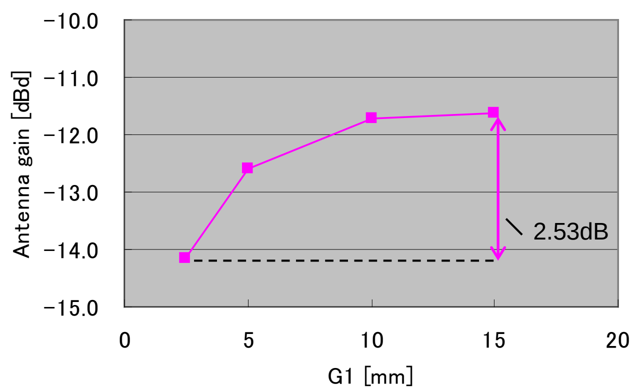


Fig.2-2. Average antenna gain of YZ-plane V-pol. versus distance G1

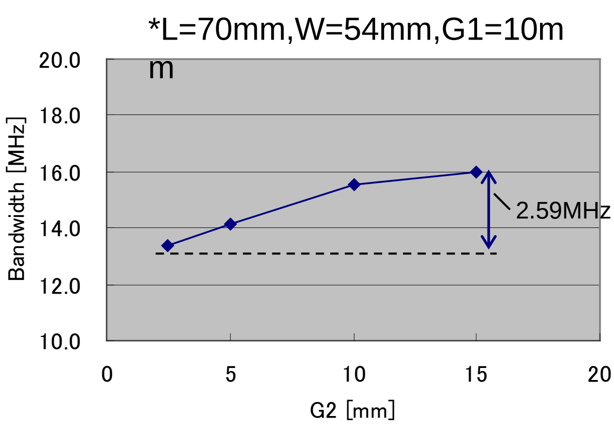


Fig.2-3. Bandwidth versus distance G2

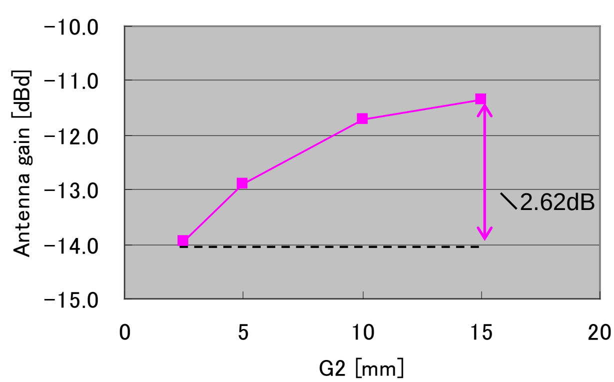


Fig.2-4. Average antenna gain of YZ-plane V-pol. versus distance G2

3. Antenna properties and the size of the GND area

In this experiment a total of 15 samples with different board dimensions were prepared in order to see the influence of GND size to the antenna properties.

・It was obvious that bandwidth and antenna gain are dramatically improved by enlarging the board length as shown in Fig.3-2 and Fig.3-3. When bandwidth was widened by 9 to 17MHz the antenna gain improved by 6dB.

・It was revealed that decreasing the Width (W) and increasing the Length (L) of the GND samples improved the bandwidth and average gain. This result suggests that an oblong shaped PCB is advantageous for good antenna performance .

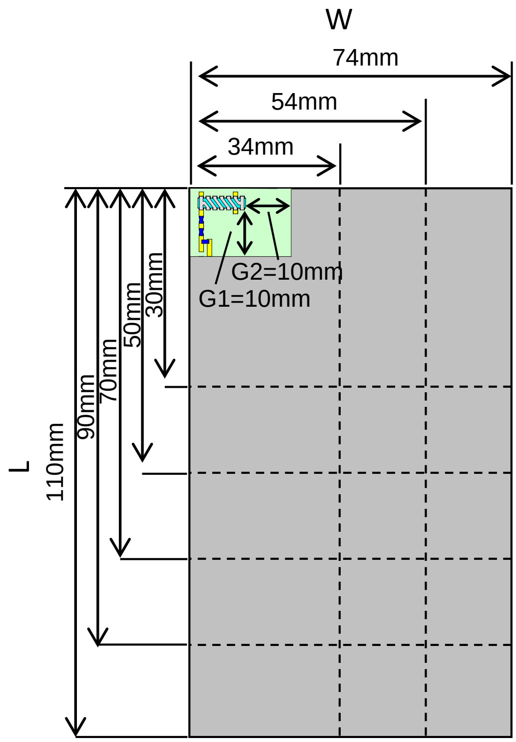


Fig.3-1. Board dimensions used in the experiment

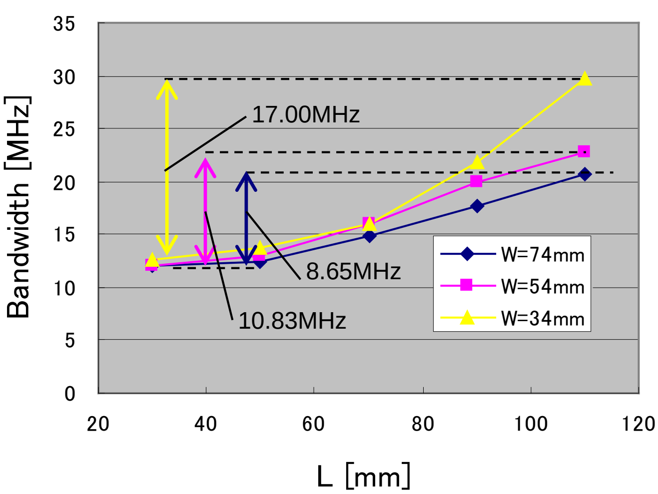


Fig.3-2. GND size dependence of band width

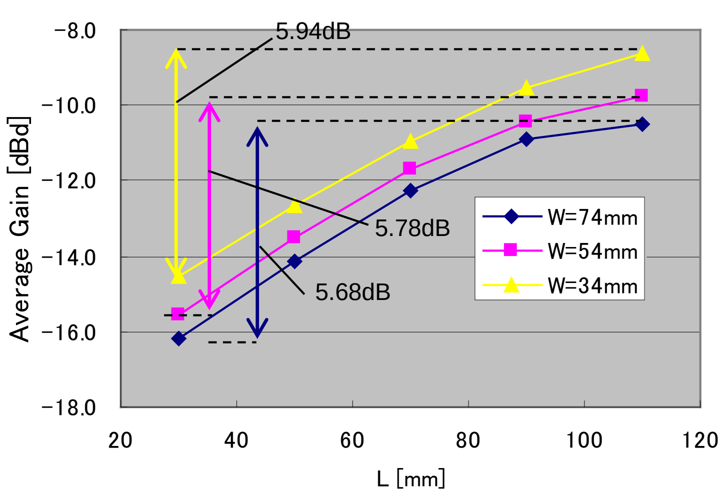


Fig.3-3. GND size dependence of average gain of V-polarized wave in YZ-plane

4. Influence of the human body

The human body has a substantial influence on the antenna performance, especially when the built-in antenna is used for mobile terminals. Therefore, quantitative antenna gain loss caused by the human body should be evaluated. In this experiment the standard sample board explained in section 1 was used.

・Fig. 4-1 and Fig. 4-2 show the VSWR property and radiation pattern of the standard antenna sample grasped by a human hand. Minimum peak of VSWR scarcely shifts from 430MHz and a 1.41 VSWR value at 430MHz. Moreover, degradation of the maximum antenna gain is hardly observed in Fig. 4-2.

・ Fig. 4-3 and Fig.4-4 show the VSWR property and radiation pattern of the standard antenna sample attached to the abdomen of the human body. One plate of styrene foam with 10mm thickness was inserted between the body and the sample board considering that the actual PCB would be enclosed in a case. The VSWR property showed a frequency shift by about 5 MHz towards a lower frequency. The radiation pattern property in Fig. 4-4 indicates a unidirectional property vertically to the sample board.

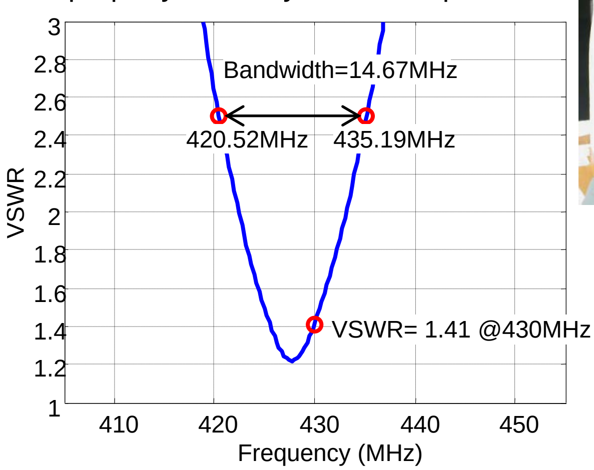
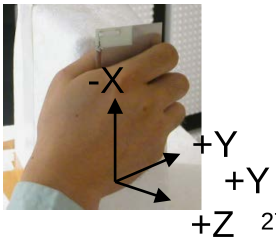


Fig.4-1. VSWR property of the standard sample grasped by hand



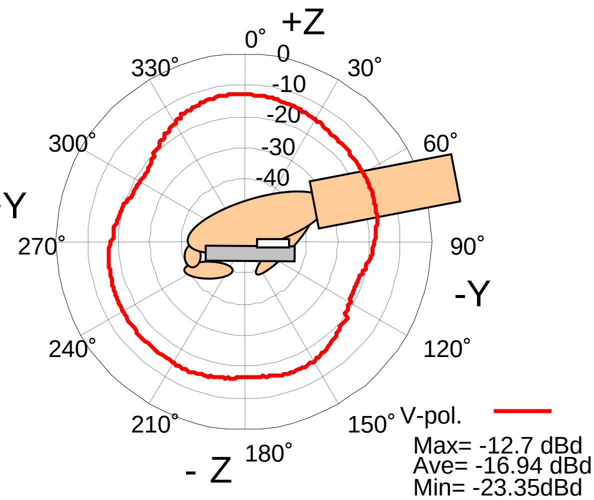
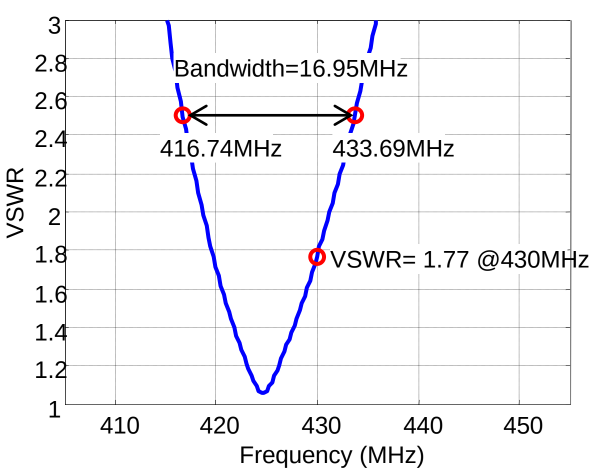
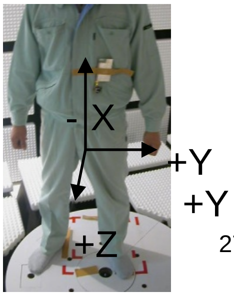


Fig.4-2. Radiation pattern of the standard sample grasped by hand





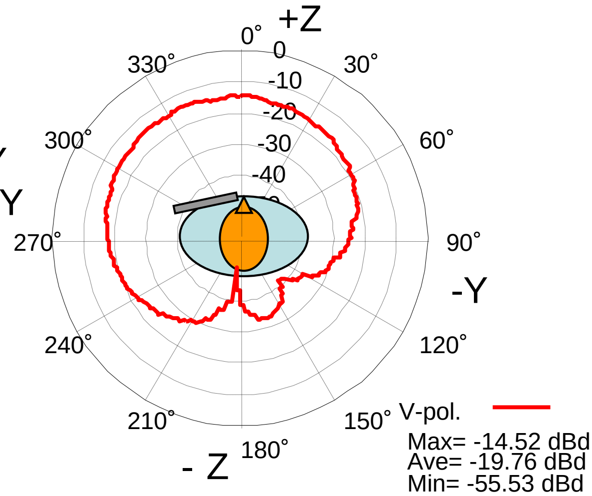


Fig.4-3. VSWR property of the standard antenna sample attached to the human body

Fig.4-4. Radiation pattern of the standard antenna sample attached to the human body

5. Antenna properties and types of chip inductors

Here, 4 kinds of chip inductors were used for tuning as specified in Table 5-1 in order to see the effect on antenna properties. Inductor chip size is 1608 (0603). Toko's chip inductor LL1608 is a multilayer type, and the other three are wound type. In this experiment antenna sample dimensions were the same as the standard antenna sample in section 1.

As shown in Table 5-1, there were few differences between antenna properties in three samples in which wound type chip inductors are used . In comparison, the sample with multilayer chip inductors has lower antenna gain by about 1.4dB. Toko's multilayer type chip inductors LL1608 have small Q values comparing to wound type as shown in Table 5-2. This low Q-value of multilayer chip inductors LL1608 results in a lower antenna gain.

Table5-1 Antenna properties dependence on the type of chip inductors

Chip Inductor		L1	L2	L1+L2	L3	VSWR	BW	Gain
type	Manufacture	[nH]	[nH]	[nH]	[nH]	at 430MHz	[MHz]	[dBd]
LQW18	Murata	24	220	244	27	1.05	16.06	−11.72
LLQ1608	Toko	1.8	220	221.8	26	1.18	17.64	−11.99
C1608	Sagami elec	0	220	220	36	1.18	16.85	−11.88
LL1608	Toko	33	150	183	47	1.25	15.21	−14.31

Table5-2 Q values of chip inductors (catalog value)

Manufacture	Type	L[nH]	Q	Test freq. [MHz]	Note
Murata	LQW18	220	40	250	Wound type
Toko	LLQ1608	220	25	100	Wound type
Sagami elec	C1608	220	25	100	Wound type
Toko	LL1608	150	20	100	Multilayer type

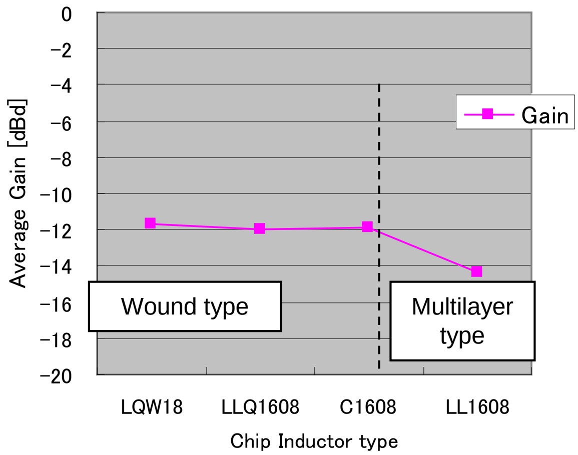


Fig.5-1.Antenna properties dependence on the type of chip inductors

6. Influence of the feeding position

Here, antenna properties of two samples with different feeding points as shown in Fig.6-1 were investigated. As shown in Table 6-1, there were few differences between the two samples. Therefore, it appears that the feeding position has little influence on the performance of the antenna.

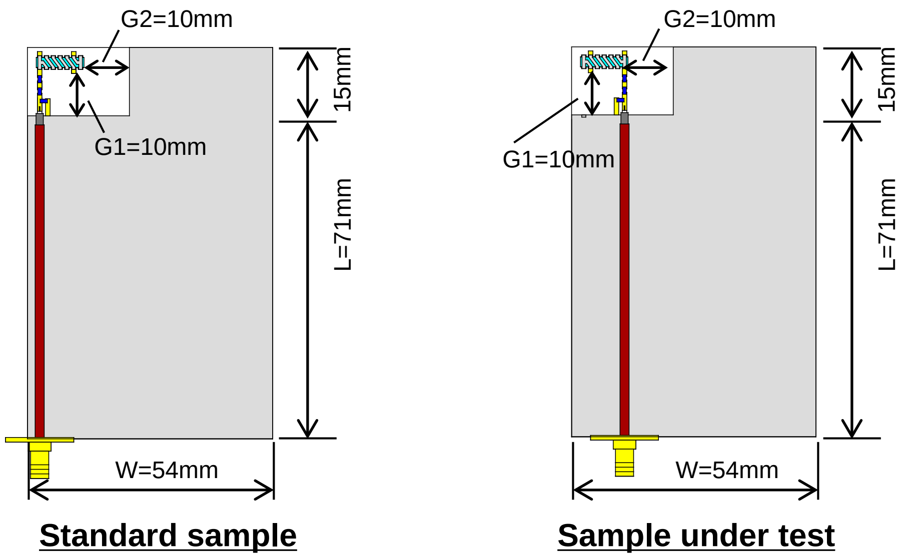


Fig.6-1.Two samples with different feeding positions

Table6-1 Antenna properties comparison between 2 samples with different feeding points

Sample	VSWR at 430MHz	BW [MHz]	Gain [dBd]
Standard sample	1.05	16.06	−11.72
Sample under test	1.06	15.73	−12.17

7. Influence of metallic plates

In this experiment, the degradation of antenna properties was evaluated when the antenna sample board was set close to a metallic plate. The sample board used here was the standard antenna sample as described in section 1. The antenna sample board was attached to the center of a 500mm×300mm sized copper plate (see Fig.7-1) and the copper plate was set on a turn table in the anechoic chamber. The gap between the copper plate and the antenna sample board varied 10mm, 20mm, 30mm, 50mm and 100mm.

・VSWR properties corresponding to the gap length between the copper plate and the antenna sample is shown in Fig.7-2. The VSWR value at 430MHz and the maximum gain dependence on the gap length is shown in Fig.7-3. When the antenna sample was positioned 10mm from the copper plate, the maximum gain of V polarization in YZ plane becomes –30.07dBd, which is inferior to the original by no less than 18dB. Furthermore, resonance frequency shifts about 13MHz towards low frequency side. By enlarging the gap length from the copper plate the antenna gain recovers dramatically.

・Since the degradation of antenna properties at 10mm distance was so significant, the antenna was retuned in the state of being set 10mm distant from the copper plate. VSWR property shown in Fig 7-4 was the result of optimization. When the radiation pattern was measured in this state, average gain only improved 1.3dB as shown with a red plot in Fig.7-3.

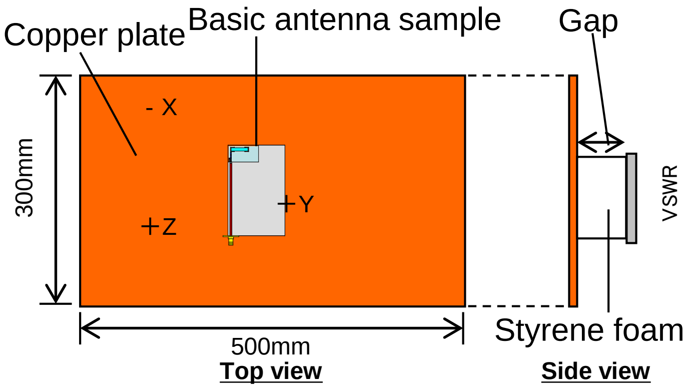


Fig.7-1.Dimensions of copper plate

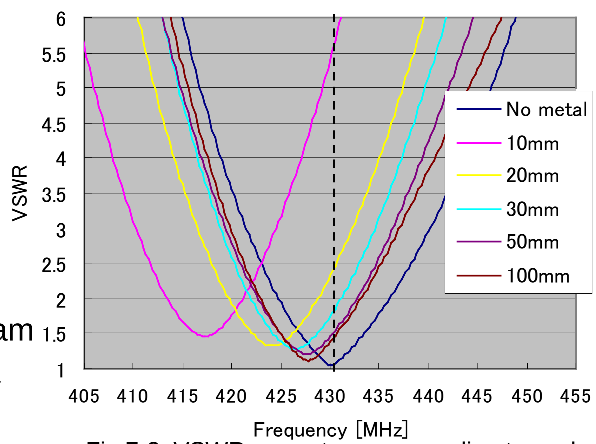


Fig.7-2. VSWR property corresponding to each gap length between the copper plate and the sample

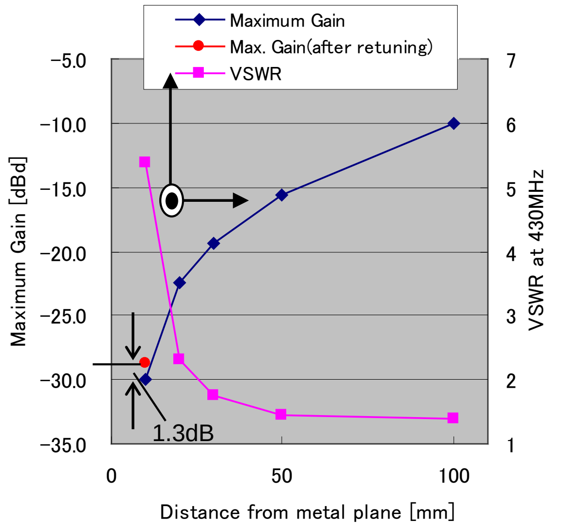


Fig.7-3. Maximum gain and VSWR at 430MHz versus gap between the copper plate and the sample

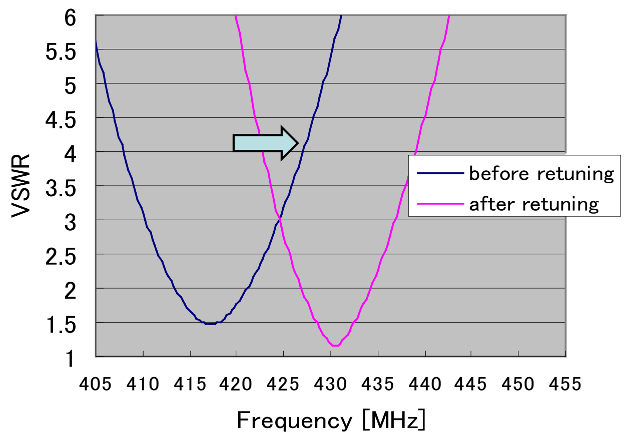
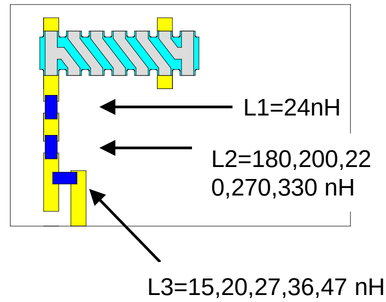


Fig.7-4.VSWR property when the sample was retuned under the condition of being set at 10mm distance from the copper plate

8. VSWR properties and chip inductors

This section shows how VSWR properties are related to 3 chip inductors. The chip inductors L1 and L2 are mounted in series with the feed point and one of the terminals of the chip antenna and used to adjust the resonance frequency. The chip inductor L3 inserted in parallel between the feed point and GND is for impedance tuning. The sample board used here has the same dimensions as the standard antenna sample explained in section 1.



・Fig.8-1 shows the change of VSWR properties when L3 is varied and L1 and L2 are fixed. While minimum peak frequency hardly changes, VSWR value becomes larger than 1 when replacing L3 from the optimal value 27nH as shown in Fig.8-2.

・Fig.8-3 indicates that a change of L2 can make resonance frequency shift higher or lower without making the minimum VSWR value larger. Fig.8-4 shows resonance frequency dependence on the value of L1+L2. This result tells us that resonance frequency shifts 0.76MHz to the lower side as L3 increases by 1nH.

L1=24nH, L2=220nH

Fig.8-1.VSWR properties corresponding to various L3

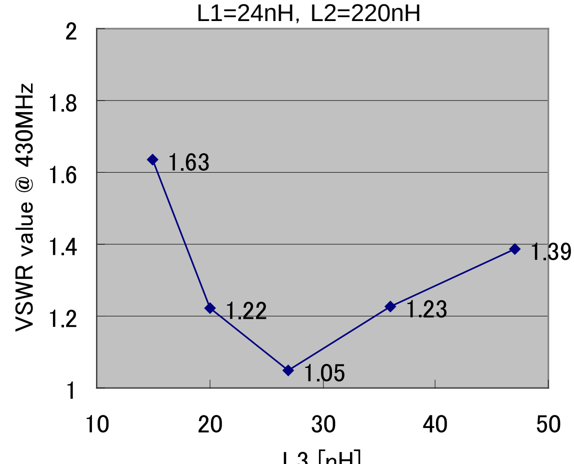


Fig.8-2. Change of VSWR value at 430MHz corresponding to various L3

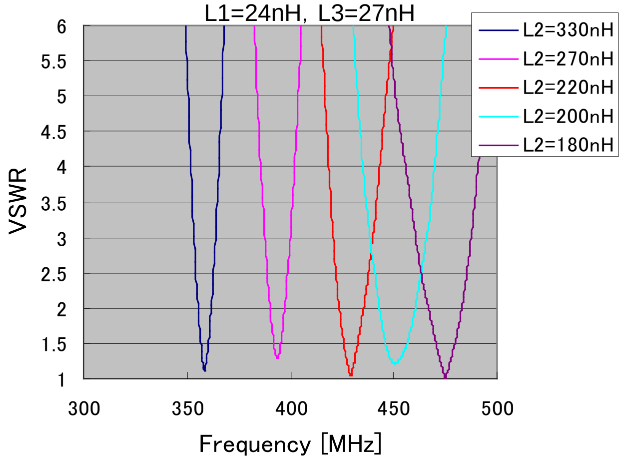


Fig.8-3.Change of VSWR properties(impedance) with various L3 values

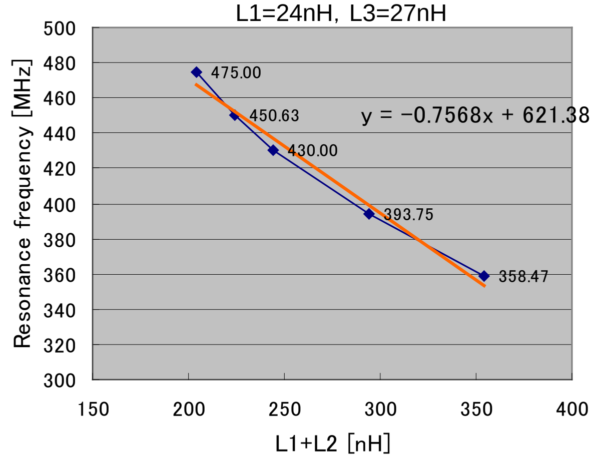


Fig.8-4.Resonance frequency dependence on the L1+L2 value

9. Method of selecting chip inductors for optimized performance

1. Mounting initial value of chip inductors L1,L2 and L3

At first, check initial resonance frequency and impedance property (minimum VSWR value) after mounting initial values of chip inductors.

・As an initial set of chip inductors, the same value set of the standard antenna in section 1 is recommended. These are L1=24nH,L2=220nH and L3=27nH. Though antenna properties are depending on the various conditions of PCB and so on, antenna resonance will appear in the frequency range of 430 ±50MHz under most conditions with this inductor set. Here, be sure to check whether resonance frequency is higher or lower than the target and how much larger the minimum VSWR value becomes.

2. Frequency tuning with L1 and L2

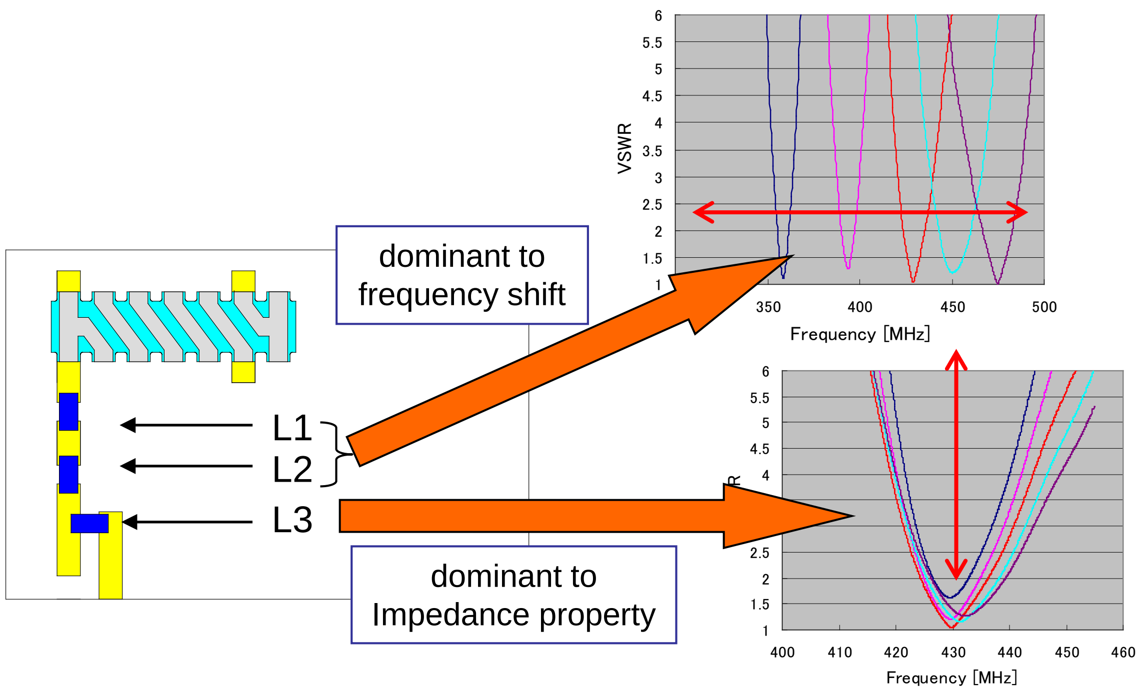
In this stage, L1 and L2 will be optimized. The chip inductor L3 is fixed here, since it has very minimal influence on the frequency shift.

・If the resonance frequency is higher or lower than your target frequency, replace the initial L1 or L2 to higher or lower one, respectively. Here the result of Fig.8-4, which represents the resonance frequency dependence on L1+L2, will help you to select an optimal combination of L1 and L2.

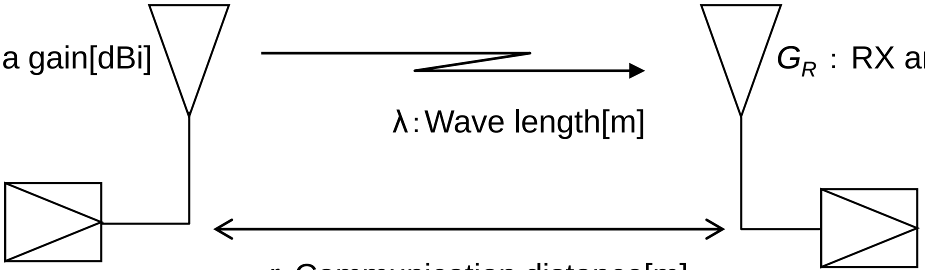
3. Impedance tuning with L3

In this stage, optimization of chip inductors will be completed. After optimizing L1 and L2, VSWR property will have a minimum peak at target frequency. However minimum VSWR value will not be close to 1, in other words impedance is not tuned to 50 ohm yet. The chip inductor L3 can optimize this impedance characteristic.

・If the minimum peak value of VSWR is not small enough, L3 should be optimized. Please refer to the results of Fig. 8-2 in order to know how L3 value affects the VSWR properties.



10. Estimation of communication distance



$$S = 10\log_{10}(kBT_0) + F + SNR$$

①L_{Pass}: Propagation loss[dB] $L_{Pass} = 10\log_{10}\left(\frac{4\pi r}{\lambda}\right)^2$

②L_{fade}: Fading margin[dB]

in case of line-of-sight≒10 (Rice Fading)

Non-line-of-sight or mobile≒20(Rayleigh Fading)

k: Boltzman Constant

T_0: Operating Temperature[K]

B: IF band width[Hz]

F: Noise factor of receiver[dB]

SNR: SN ratio of a baseband signal[dB]

Calculation method

Here we have a basic equation of radio link calculation in free space.

$$S = P_0 + G_T + G_R - L_{pass} - L_{fade}$$

Therefore an acceptable propagation loss can be expressed below.

$$L_{pass} = P_o + G_T + G_R - L_{fade} - S$$
$$= 10\log_{10}\left(\frac{4\pi r}{\lambda}\right)^2$$
$$= 20\log_{10}\left(\frac{4\pi f r}{c}\right)$$
$$= 20\log_{10}\left(\frac{4\pi \cdot 10^6}{c}\right) + 20\log_{10}(f) + 20\log_{10}(r)$$
$$= -27.6 + 20\log_{10}(F) + 20\log_{10}(r) \quad , f[MHz]$$

Therefore the maximum communication distance r is the one that satisfies the relations below.

$$L_{pass} \geq -27.6 + 20\log_{10}(f) + 20\log_{10}(r)$$

In actual propagation, rather than free space, communication distance falls and is estimated by the following formula.

$$L_{pass} \geq -27.6 + 20\log_{10}(f) + N \cdot 10\log_{10}(r)$$

N: path gain exponent

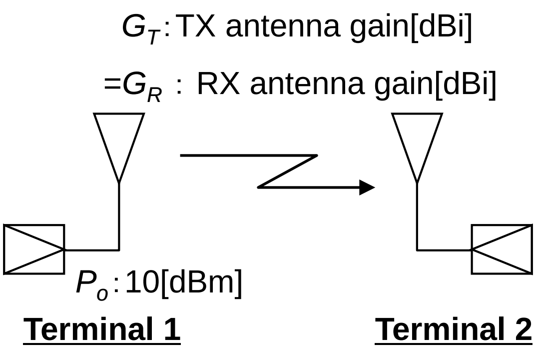
2=Free space, 2.5=UHF propagation in a height of 1.5m, 3=large office

Finally the target expression of relations can be obtained as follows.

$$r = 10^{\frac{L_{pass} + 27.6 - 20\log_{10}(f)}{10 \cdot N}}$$

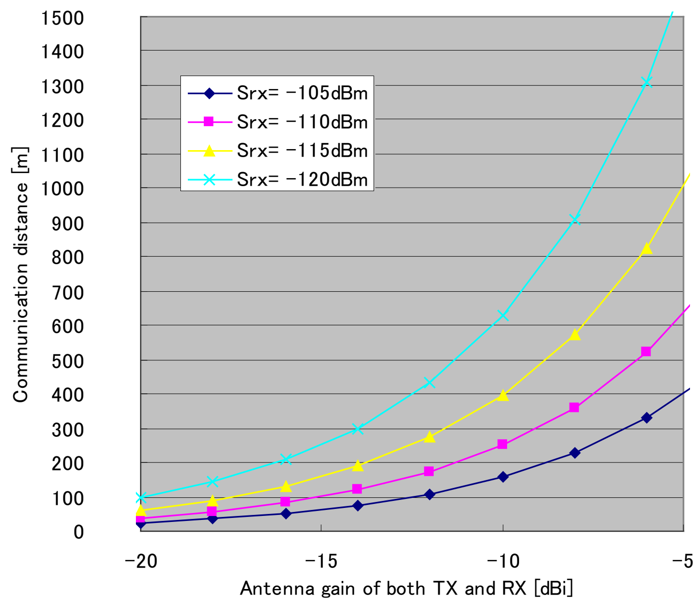
(Calculation example of communication distance)

1) Communication between 2 terminals which have antenna with same performance

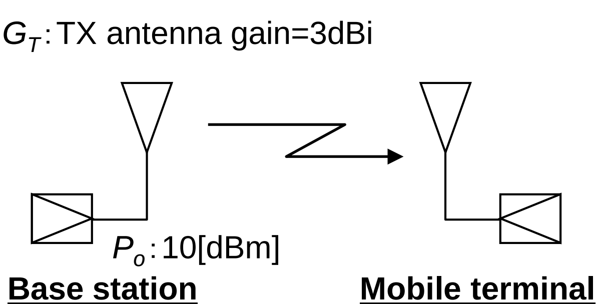


Calculation conditions

- Fading margin: 15dB
- Path gain exponent: 2.5
- CW frequency: 430MHz

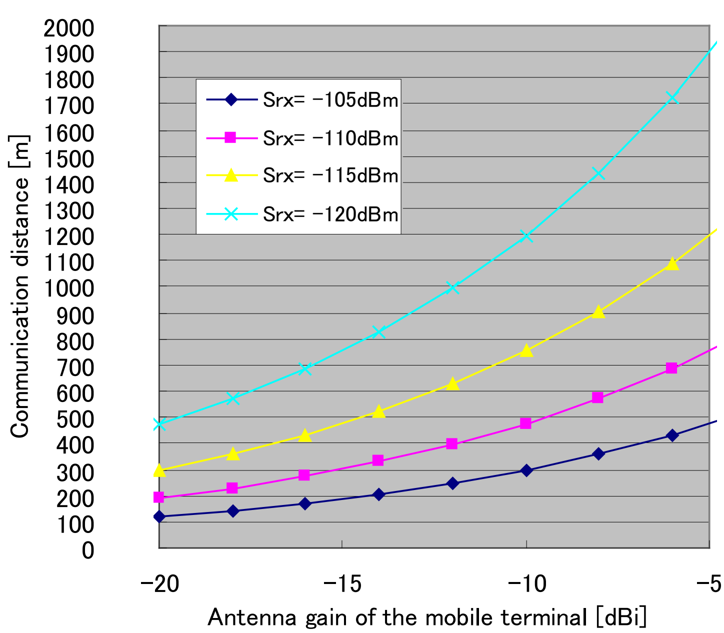


2) Communication between the base station and the mobile terminal



Calculation conditions

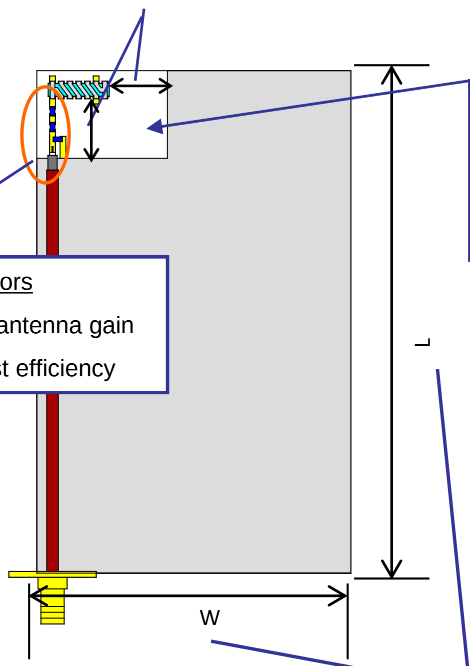
- Fading margin: 15dB
- Path gain exponent: 2.5
- CW frequency:430MHz



11. Instruction for designing PCB and location of parts for the better antenna performance

<u>Antenna distance from GND and size of GND</u>

This gap should be as large as possible for better antenna performance.



<u>Other electrical components</u>

Do not mount any electric part in this GND area except for the antenna elements. Try to keep electrical components as far away as possible.

<u>Type of chip inductors</u>

Wound type: High antenna gain

Multilayer type:Cost efficiency

<u>PCB dimensions</u>

Try to make the width (W) as narrow as possible and the length (L) as long as possible.

Other tips

・Antenna resonance frequency shifts towards lower frequency under the influence of the human body. So if AM11DP-ST01 is applied to the remote controller, which mainly works in contact with the human body, the antenna should be tuned under the condition of touching the human body.

・Antenna gain becomes considerably worse when the wireless terminal with AM11DP-ST01 is set close to metallic objects such as a wall or door. Therefore, in this case, wireless terminals should be placed as far as possible from metallic objects.

・In a practical wireless terminal, a circuit board will be enclosed in a case made of plastic. This plastic case has a tendency to make resonance frequency shift lower. In a situation such as this, tuning should be done under conditions where the circuit board is enclosed in a plastic case.

・If the circuit board has a 2 or 3 stage structure and the AM11DP-ST01 is mounted on one of them, not only the mounted antenna PCB but also the other PCB should have GND stripped areas around the AM11DP-ST01 so as not to shield the radiation from the antenna in any direction.