Understanding the Antenna

(Operation And Specifications)

PHYCHIPS

Introduction

The antenna is one of the most important components in the design of an RF device.

In particular, in RFID, the antenna plays a large part in determining the recognition distance and range, and the size of the device.

If you select an antenna that is not suitable for the purpose of the device and design the device without considering various factors that affect the performance of the antenna, unintended performance degradation may occur, and in severe cases, redesign becomes unavoidable.

This document will help you understand the operation of the antenna by explaining the basic parameters of the antenna and telling you the need for antenna matching. So, the engineer will be able to select an appropriate antenna in consideration of the usage environment, operation scenario, and design an RFID device that can achieve the optimum performance of the antenna.

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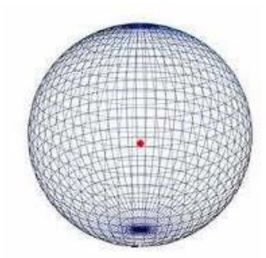
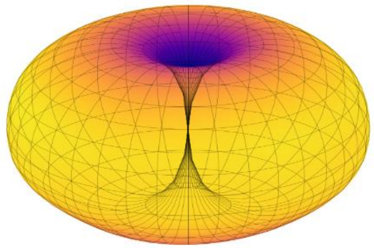
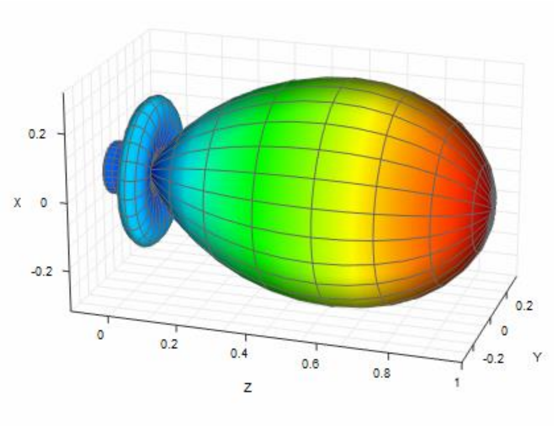
1. Antenna Radiation Pattern



Isotropic Antenna



Omnidirectional Antenna



Directional Antenna

1) Isotropic Antenna

- Antenna that radiates electromagnetic waves in the same size without loss in all directions.
- A theoretical form that cannot be produced.

2) Omnidirectional Antenna

- An antenna whose radiation in one plane has directionality at 360° but does not have directionality in a direction orthogonal to that plane.
- The radiation pattern is a donut shape, and the antenna has a general dipole shape.
- In RFID, it is used for short-range applications.

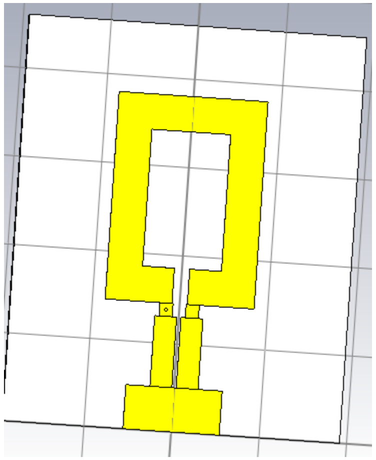
3) Directional Antenna

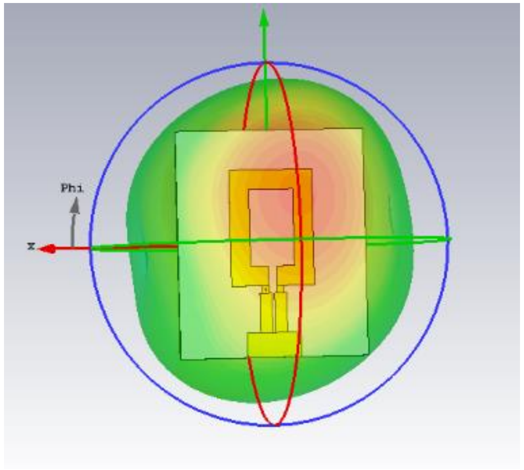
- An antenna that radiates in a certain direction with a larger magnitude than in the other direction.
- Radiation is directional by emitting or receiving more power in the required direction and reducing interference from other undesired directions.
- Applicable to QUBE series and ceramic antenna
- Used for general RFID reader devices (fixed type, gun-type reader, PDA/cell phone reader, etc.).

2. Antenna Type

1) PCB antenna

- An antenna that draws a pattern on the PCB and radiates at a desired frequency.
- Can be implemented in various forms depending on the frequency and usage environment.
  : Loop type, straight type, F type (PIFA), meander F type (MIFA), etc.
- Two-dimensional (2D) structure on the same plane as the PCB.
  : Advantages: Can be implemented in a small space. Low manufacturing cost.
  : Disadvantages: Low efficiency. Must comply with design rules such as pattern design and matching circuit.
- Since it does not have directivity, tags around it can be read outside of the desired direction.
  Usually used for short-range applications such as tag targeting of a single tag with a short distance.

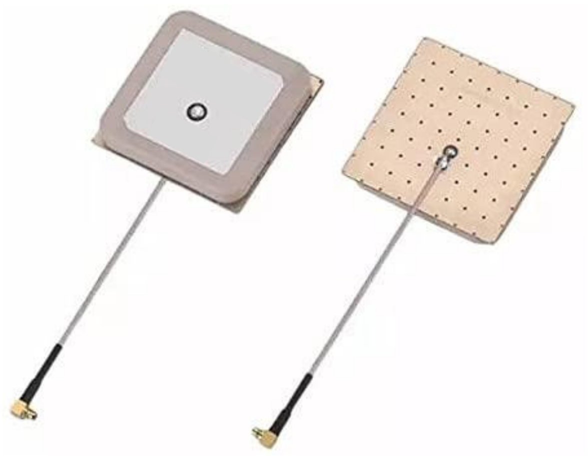




2. Antenna Type

2) Ceramic Antenna

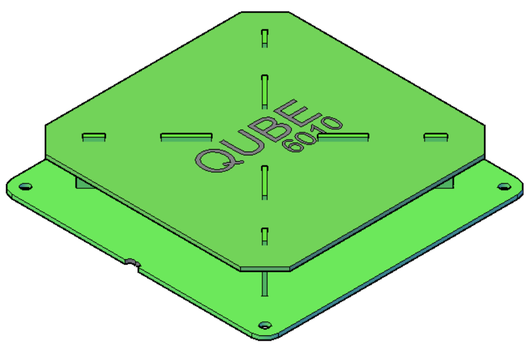
- An antenna type fed with a pin by coating silver on the surface using ceramic.
- Microstrip patch antenna type using square ceramic dielectric is widely used.
- It is relatively inexpensive and can be miniaturized by using a high dielectric constant ceramic dielectric, so it can be installed in a narrow space.
- Since the bandwidth is narrow and there are changes in frequency and radiation characteristics depending on the enclosure, it can be expected to operate normally only after appropriate matching in an enclosure.
- There are two types:
  - A type used by placing it on the PCB like a pin type component on the main board.
  - A ceramic antenna + PCB + cable assembly type.

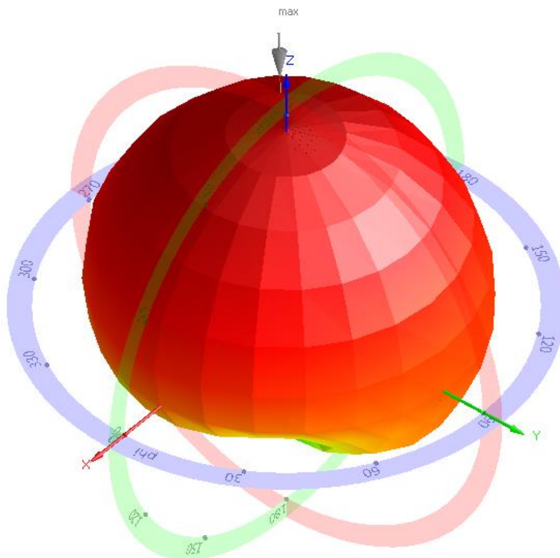


2. Antenna Type

3) QUBE series

- QHA (Quadrifilar Helix Antenna) structure: 4 antennas are arranged in a spiral shape.
- Cube-shaped structure antenna that can be used inside or outside the device.
- Advantages such as high efficiency, low hand effect, compact size, wide bandwidth, wide beamwidth, circular polarization, and decent axial ratio.
- It is a directional antenna with high gain and is specialized for RFID tag targeting. Single tagging in the desired direction, multi tagging can be used without significant restrictions.





2. Antenna Type

4) RFID Reader Antenna Selection

	PCB	Ceramic 2504	Ceramic 3404	QUBE4010	QUBE6010	QUBE6015
Size	Small Type	25x25x4T	34x34x4T	48x40x10T	60x60x10T	60x60x15T
Polarization	Linear	Circular				
Gain	<-3dBiL	+0dBic	+1dBic	+1dBic	+2.5dBic	+3.5dBic
-3dB Bandwidth	10~20MHz	3MHz	5MHz	20MHz	28MHz	33MHz
Handeffect	Weak			Strong		
Read range	<5cm	1m	1.8m	1.8m	2.8m	3.8m
Assembly	No limitation	Need PCB+Cable		Screw or Double-Sided Tape		

3. Datasheet Analysis

Electrical Specifications

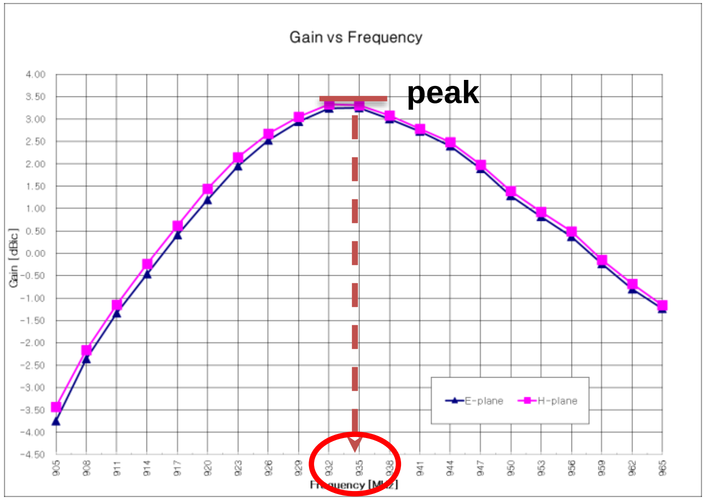
Item	Specifications			
	Min.	Typical	Max.	Unit
Center Frequency (= Fc)	931	935	939	MHz
Operation Frequency	902	915	928	MHz
3dB Bandwidth	26	30		MHz
Return Loss @ Fc			-15	dB
Polarization	R.H.C.P			
Peak Gain @ Fc (RHCP)		3		dBic
Axial Ratio	1.5	1.3		

1) Center Frequency: Center frequency of the antenna
2) Operating Frequency: Operating frequency when installed to an enclosure
3) -3dB Bandwidth: The frequency range in which the power is ½ from the peak
4) Return Loss: Value converted from reflection coefficient (VSWR) into log scale (dB) of power
5) Polarization: Polarization characteristics of the antenna. Linear, Circular (RHCP, LHCP)
6) Radiation Pattern: The shape of the antenna radiating
7) Peak Gain: The highest value of the gain of the antenna
8) Axial Ratio: The ratio of the major axis and the minor axis of the polarization

3. Data Analysis

1) Center Frequency

- The center frequency of the antenna refers to the frequency at which the gain is peak.
- It is linear antenna if the point where S11 (return loss) is the lowest most coincides with the center frequency.
- In the case of circular antennas, they may not match.



Gain vs. Frequency Data

2) Operating Frequency

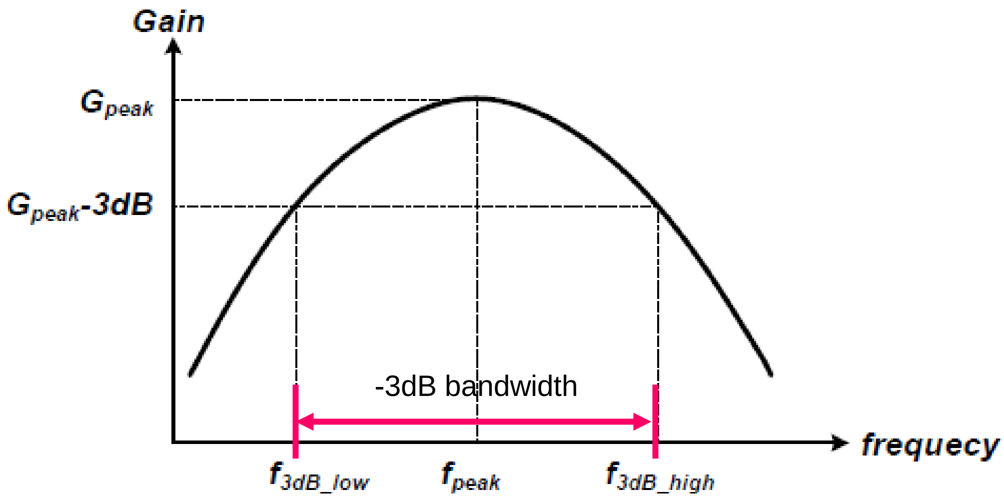
- The frequency range in which the antenna operates within the housing(enclosure).
- In general, the frequency band of the used application is indicated.

Ex) RFID: US (902~928MHz), KR (917~923MHz), EU(865~868MHz)

3. Data Analysis

3) - 3dB Bandwidth

- The range of frequencies where the antenna power is ½ from the peak (-3dB).
- Usually used as an index to indicate the range in which the antenna operates.
- The range of operation frequency includes the center frequency of the antenna and it is judged that the antenna is well selected and can operate normally when it is within the -3dB bandwidth.



3. Data Analysis

4) Return Loss and VSWR(Voltage Standing-Wave Ratio)

- Return Loss measures the ratio of the signal transmitted to the antenna ($P\_incident$) and the signal reflected toward the input ($P\_reflectete$). The value is expressed in dB.

$$Return\ Loss(dB) = 10\log\left(\frac{P_{incident}}{P_{reflected}}\right)$$

- It indicates the size of the signal that the signal transmitted to the antenna is not radiated but reflected, and shows how well the antenna is matched to 50 ohms. The 50 ohm perfectly matched antenna radiates most of the transmitted signal through the antenna without any loss.

- VSWR is a value calculated simply as the ratio of the input voltage to the reflected voltage by the amount of reflection generated by the difference in impedance at a certain connection. Smaller means less reflection.

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{V_{input} + V_{reflected}}{V_{input} - V_{reflected}} \qquad Return\ Loss = 20\log\left(\frac{VSWR-1}{VSWR+1}\right)$$

- Normally, Return Loss is manufactured as -15 ~ -18dB, which means VSWR is 1.4 ~1.3 and input signal is radiated through antenna over 98%.

3. Data Analysis

- In general, the antenna is manufactured with a VSWR of 1.3 or less, which means that the return loss is -18dB or less, and the input signal is radiated through the antenna over 98%.

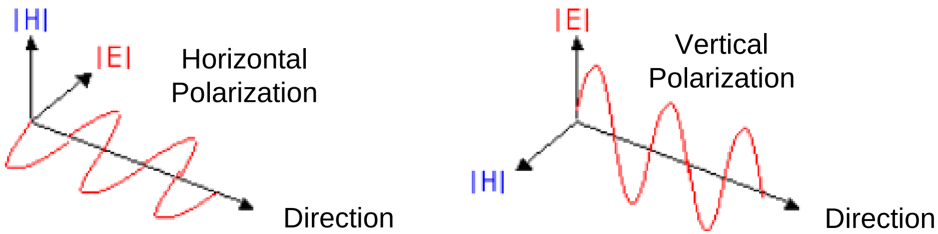
VSWR	Return Loss (dB)	Mismatch Loss (dB)	Power transmitted Efficiency (%)
1.011	-45	0	100
1.02	-40	0	99.99
1.036	-35	0.001	99.97
1.065	-30	0.004	99.9
1.12	-25	0.014	99.68
1.22	-20	0.044	99
1.29	-18	0.069	98.42
1.38	-16	0.11	97.49
1.5	-14	0.176	96.02
1.67	-12	0.283	93.69
1.92	-10	0.458	90
2.32	-8	0.749	84.15
3.01	-6	1.256	74.88
4.42	-4	2.205	60.19

VSWR Return Loss VS. **Power Transmitted Efficiency**

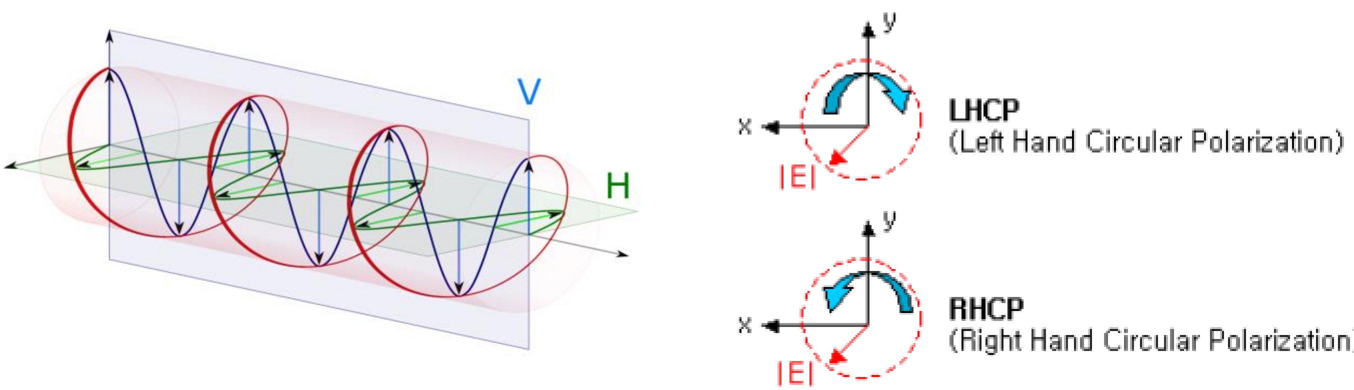
3. Data Analysis

5) Polarization

- Polarization refers to the direction of the polarity of the E-field with respect to the propagation direction of the electromagnetic wave in the antenna. It has its own polarization shape according to the shape of the antenna, and is largely classified into two categories: Linear Polarization and Circular Polarization.
- Linear Polarization has two types: horizontal polarization and vertical polarization depending on the direction, and circular polarization has two types: RHCP (Right Hand Circular Polarization) and LHCP (Left Hand Circular Polarization) depending on whether the rotation direction is right or left.



Linear Polarization

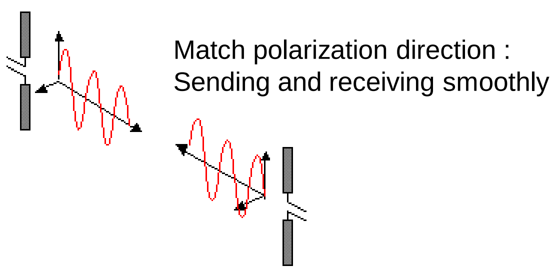


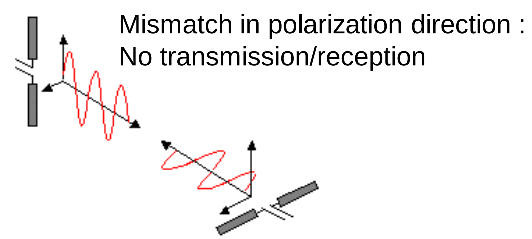
Circular Polarization

3. Data Analysis

- Polarization of RFID Reader Antenna and Tag

  - Tag is also an antenna, so it has polarization. In general, it has a dipole shape, so it is linear.
  - When the polarization directions of the RFID reader antenna and the tag match each other, transmission/reception is smooth. Conversely, if the polarization directions are different from each other, the transmission/reception performance deteriorates. At worst, if they have polarizations that are completely orthogonal to each other, there is no signal exchange.

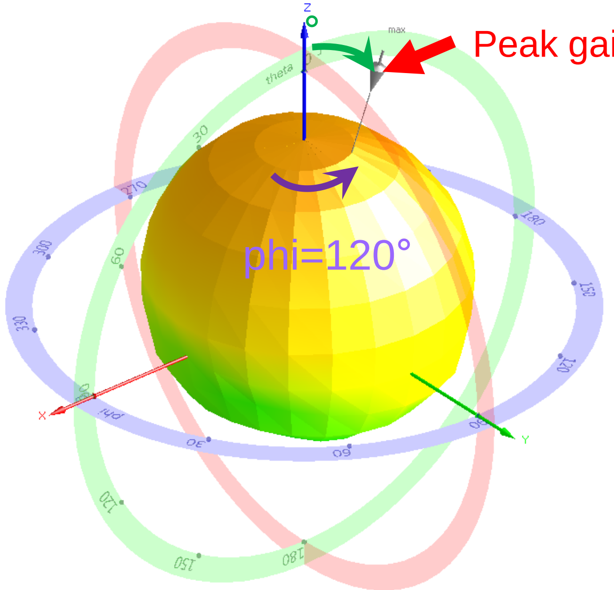




  - In order to prevent mismatch in polarization direction like this, one reader antenna or tag should have circular polarization. Usually, in the case of tag, linear type is used a lot for reasons of size and price, so reader antenna is used as circular.

3. Data Analysis

6) Peak Gain



		RHCP				
No.	Freq.	Eff.[%]	Avg.[dBic]	Peak[dBic]	Theta[	Phi[de
1	904.000	49.82	-3.03	2.17	15.00	105.00
2	906.000	53.96	-2.68	2.49	15.00	105.00
3	908.000	57.99	-2.37	2.76	15.00	120.00
4	910.000	61.31	-2.12	2.98	15.00	105.00
5	912.000	63.45	-1.98	3.10	15.00	120.00
6	914.000	64.29	-1.92	3.14	15.00	120.00
7	916.000	64.14	-1.93	3.12	15.00	120.00
8	917.000	63.72	-1.96	3.05	15.00	105.00
9	918.000	63.10	-2.00	3.00	15.00	120.00
10	919.000	62.23	-2.06	2.93	15.00	120.00
11	920.000	61.16	-2.14	2.84	15.00	120.00
12	921.000	59.88	-2.23	2.73	15.00	105.00

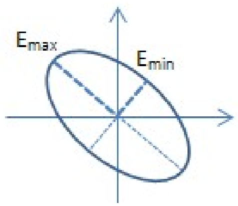
Antenna Data Measured in Chamber

- The measured antenna is a circular antenna, the peak gain is 3.14dBic, and the frequency at this time of 914MHz is the center frequency.
- It is a directional antenna that radiates in the +Z direction, and the peak gain location is theta 15°, phi 120°
- The current measurement value is measured at 15° intervals, and a more accurate value can be obtained by narrowing the interval.

3. Data Analysis

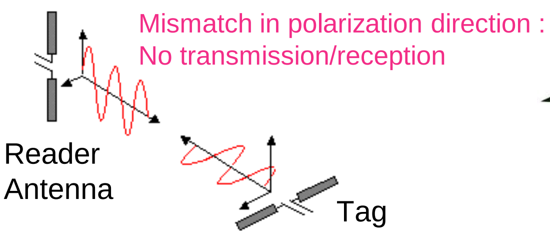
7) Axial Ratio

- It means the axial ratio of polarization in a circular polarized antenna.
  Displayed as the ratio of the small axis to the large axis.

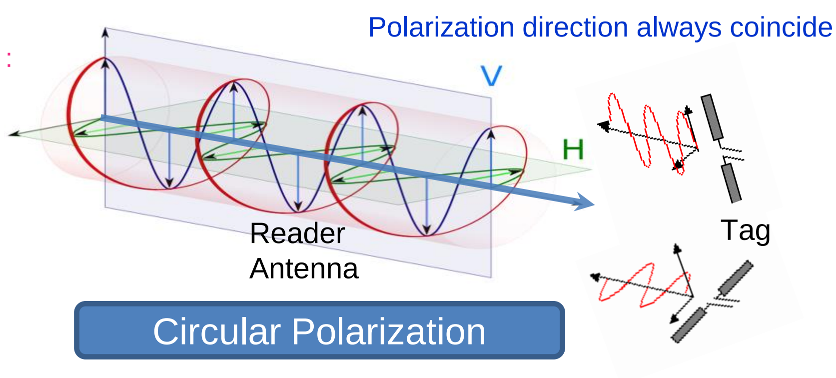


$$AR\ (Axial\ Ratio) = E_{max}\ /\ E_{min}$$

- An antenna with an AR of 1 cannot be made, and in general, a circular antenna shows an elliptical polarization form. The lower the axis ratio, the less the difference in performance depending on the angle of the receiving (or transmitting) antenna.
- Since tags in RFID are generally linear antennas, a circular antenna with good AR should be used for the reader antenna. Otherwise, the tag may not be read at an angle or null, or the read range may vary depending on the angle of the tag.



Linear Polarization



Circular Polarization

3. Data Analysis

8) Radiation Pattern

		RHCP					H(Theta=!				E1(Phi=0)				E2(Phi=90		
No.	Freq.	Eff.[%]	Avg.[dBic]	Peak[dBic]	Theta[(	Phi[de(	Avg.[dBic	Peak[dBic]	[deg]	BW[deg]	Avg.[dBic	Peak[dBic]	Theta[(	BW[deg]	Avg.[dBic	Peak[dBic]	Theta[(
1	904.000	49.82	-3.03	2.17	15.00	105.00	-4.56	-2.87	240.00	283.24	-2.77	1.64	0.00	126.05	-1.99	2.13	15.00
2	906.000	53.96	-2.68	2.49	15.00	105.00	-4.20	-2.53	240.00	286.24	-2.41	1.98	0.00	126.30	-1.66	2.45	15.00
3	908.000	57.99	-2.37	2.76	15.00	120.00	-3.87	-2.22	240.00	289.27	-2.08	2.29	-15.00	126.83	-1.37	2.73	15.00
4	910.000	61.31	-2.12	2.98	15.00	105.00	-3.62	-1.98	240.00	290.54	-1.83	2.54	-15.00	127.29	-1.16	2.94	15.00
5	912.000	63.45	-1.98	3.10	15.00	120.00	-3.44	-1.76	225.00	291.44	-1.67	2.67	-15.00	127.72	-1.03	3.05	15.00
6	914.000	64.29	-1.92	3.14	15.00	120.00	-3.37	-1.70	225.00	293.57	-1.59	2.76	-15.00	127.70	-0.99	3.08	15.00
7	916.000	64.14	-1.93	3.12	15.00	120.00	-3.36	-1.68	225.00	295.52	-1.59	2.77	-15.00	127.89	-1.02	3.04	15.00
8	917.000	63.72	-1.96	3.05	15.00	105.00	-3.38	-1.68	225.00	295.27	-1.62	2.72	-15.00	128.23	-1.06	2.99	15.00

Antenna Data Measured in Chamber

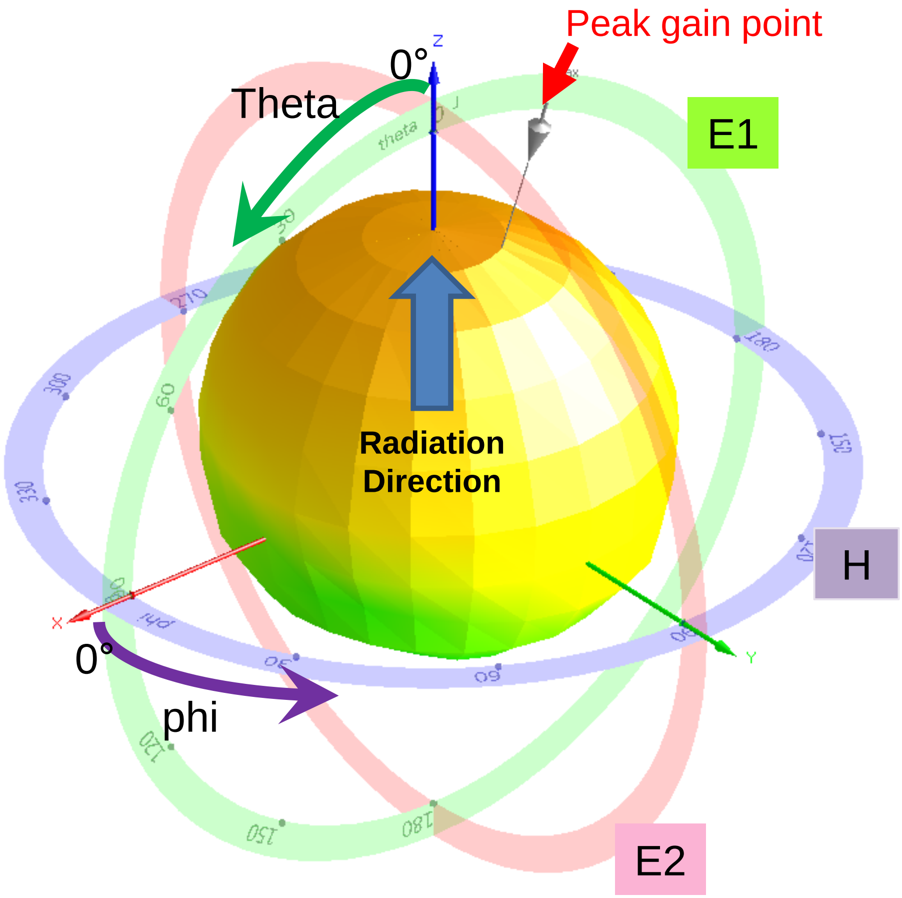
- Freq. : Measuring Frequency
- Eff.[%] : Efficiency
- Avg.[dBic] : 360 degree average value of gain
- Peak[dBic] : The highest value of gain
- Theta[deg] : Theta angle of the peak point
- Phi[deg] : Phi angle of the peak point

- RHCP :

  RHCP component data of vector sum of E plane and H plane
- H(theta=90°) :

  Data of the x-y plane, the horizontal plane of the antenna
- E1(phi=0°) : Data of x-z plane, antenna vertical plane 1
- E2(phi=90°) : Data of y-z plane, vertical plane 2 of antenna

3. Data Analysis

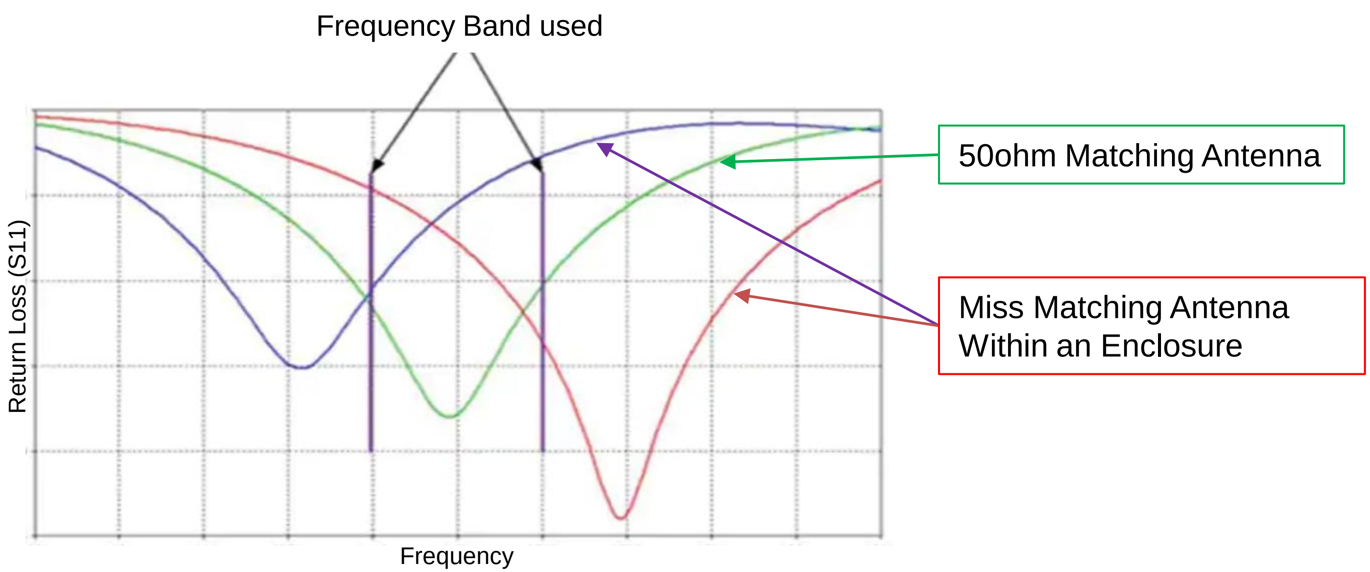


- +z axis : Radiation direction of antenna
- H(theta=90°) : Horizontal plane, x-y plane
- E1(phi=0°) : Elevated plane 1, x-z plane
- E2(phi=90°) : Elevated plane 2, y-z plane

4. Antenna Matching

1) Antenna Miss Matching

- Antenna is an element in which the signal transmitted from the input port is radiated in the form of radio waves. In order to maximize radio wave radiation and minimize return loss, the impedance of the antenna should be made as close as possible to 50 ohms. This is called antenna matching.
- Even if a well-manufactured antenna for 50 ohms at the desired frequency is also mounted in the housing, the impedance of the antenna is changed due to the surrounding environment such as the material of the device, the distance from the antenna, and the parts inside the device, so that it operates out of the desired frequency. This is called miss matching of the antenna.
- Miss-matched antennas cannot achieve maximum performance in the desired band because the center frequency is out of the used frequency band.

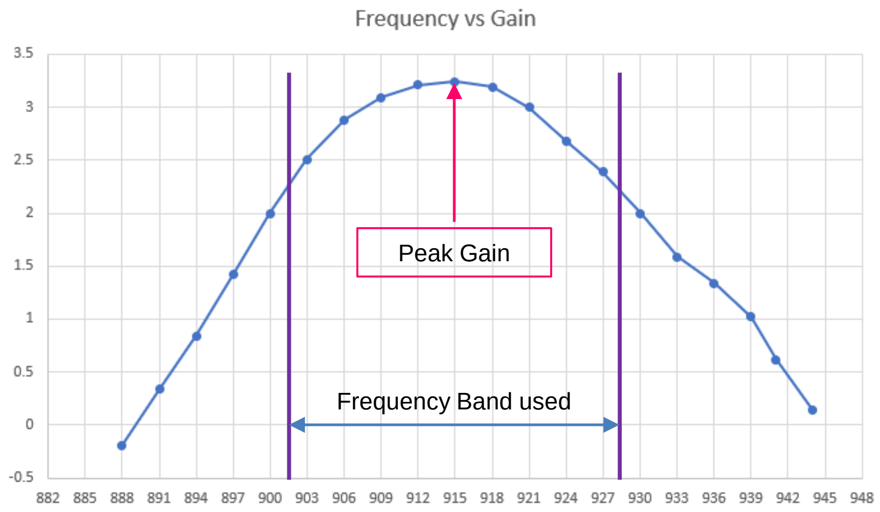


Return Loss of changing antenna after assembled in housing (S11)

4. Antenna Matching

2) Antenna Matching Within an Enclosure

- While the antenna is mounted inside the housing, the impedance change amount due to the surrounding environment such as the apparatus is measured, and the characteristic change is made in the opposite direction as the change amount, and the impedance is intentionally miss-matched and manufactured. Then, 50 ohms are matched while the antenna is operating, and the operation can be optimized at the desired frequency.
- If there is a change in the mold of the device where the antenna is mounted, the location of the PCB, the location of the batter, etc., the impedance of the antenna is changed together and miss matching occurs. Samples that have already been produced can be operated in an unoptimized state in the modified instrument.
- Antenna matching must be confirmed with the final housing as fully assembled device.



Gain curve of the optimized antenna in the state of assembly

5. ERP & EIRP

- **Antenna gain Unit**
  - dBi: linear gain based on isotropic radiator (dipole antenna = 2.15dBi)
  - dBd: linear gain based on dipole (dipole antenna = 0dBd)
  - dBic: circular gain based on isotropic radiator
  - Normally dBi means a gain of linear antenna and is same as dBiL.

  - dBd = dBi(dBiL) – 2.15
  - dBic = dBi(dBiL) + 3
  - dBic = dBd + 5.15

* Citation
https://www.nordicid.com/resources/expert-article/rfid-reader-power-outputs
https://rfid.atlasrfidstore.com/hubfs/Content/Conversion%20Tables.pdf

5. ERP & EIRP

- **ETSI Standard**
  - Power limits up to a maximum of 2 W e.r.p. are specified for this equipment in the frequency band 865 MHz to 868 MHz and up to a maximum of 4 W e.r.p. in the frequency band 915 MHz to 921 MHz.
  - The recorded value shall be corrected for each of the antenna gains and be stated in e.r.p. To calculate the allowed conducted power with a circularly polarized antenna, formula (1) shall be used:

$$P_C = P_{erp} - G_{IC} + 5.15 + C_L \ [\, dBm] \qquad (1)$$

- P_C : interrogator conducted transmit power in dBm
- G_{IC} : antenna gain of a circular antenna in dBic
- C_L : total cable loss in dB

- Beam-width Limits

  The beam-width(s) of the antenna(s) in the horizontal orientation for the lower band shall comply with the following limits

  For transmissions ≤ 500 mW e.r.p. there shall be no restriction on beam-width

  For transmissions of > 500 mW e.r.p. to ≤ 1 000 mW e.r.p. beam-widths shall be ≤ 180º.

  For transmissions of > 1 000 mW e.r.p. to 2 000 mW e.r.p. beam-widths shall be ≤ 90º.

  (Bandwidth of QUBE series = 110º ~ 120º)

5. ERP & EIRP

- **FCC Standard**
  - FCC Section 15.247(b) deals with regulations for frequency hopping within 902–928 MHz
  - FCC Section 15.247(b) deals with maximum peak conducted output power of intentional radiators
  - For systems using digital modulation in the 902–928 MHz, 2400.0–2483.5 MHz, and 5725–5850 MHz bands, the maximum peak conducted output power of intentional radiators is 1 watt.
  - The conducted output power limit for various frequency bands is based on the use of antennas with directional gains that do not exceed 6 dBi.
  - If transmitting antennas of directional gain greater than 6 dBi are used (see Section 15.247(c)), the conducted output power from the intentional radiator shall be reduced below the stated values, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.
  - As an alternative to a peak power measurement, compliance with the 1-watt limit can be based on a measurement of the maximum conducted output power.

5. ERP & EIRP

		Region	Max power	Gain unit
ERP	Effective Radiated Power	ETSI (Lower Band)	33dBm or 2W	dBd
EIRP	Effective Isotropic Radiated Power	FCC	36dBm or 4W	dBiL

- **RED4S +QUBE6015 radiated power in each region**
  - RED4S = 27dBm
  - QUBE6015 = 3.5dBic

  - **ETSI(Lower Band)**
    - $P_{erp} = P_C + G_d = P_C + G_{IC} - 5.15$ [dBm]
    - P_{erp} = 27 + 3.5dBic - 5.15 = **25.35 dBm**

  - **FCC**
    - $P_{eirp} = P_C + G_{IL} = P_C + G_{IC} - 3$ [dBm]
    - P_{eirp} = 27 + 3.5dBic – 3 = **27.5 dBm**

  - So, dBm [ERIP] = dBm[ERP] + 2.15 ,

27.5 = 25.35 + 2.15, it is correct.

dBm [ERIP] = dBm[ERP] + 2.15
dBd = dBiL – 2.15
dBiL = dBic – 3
dBd = dBic – 3 – 2.15

P_C : output power in dBm
G_{IC} : antenna gain in dBic
G_{IL} : antenna gain in dBiL
G_d : antenna gain in dBd

Contact Information

PHYCHIPS Inc.
#104, 187 Techno 2-ro, Yuseong-gu, Daejeon, Korea (Yongsan-dong, Migun Technoworld 2), 34025
Web site : http://www.phychips.com
E-mail : sales@phychips.com
TEL : +82-42-864-2402
FAX : +82-42-864-2403