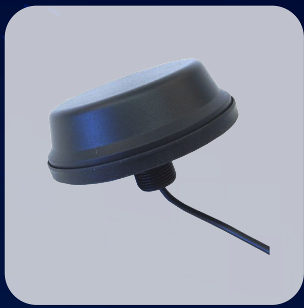

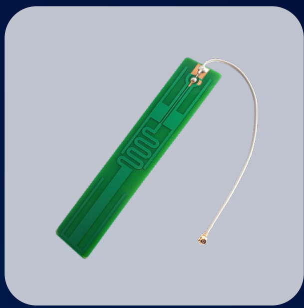

Siretta

Enabling Industrial IoT

Siretta Antennas

101 eBook

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Introduction

This antenna technical parameter guide is intended as the companion document to the data sheets describing Siretta's range of antennas. Antennas cover many applications, the most widely known and used being Television/radio, cell phones, WiFi and Bluetooth. But there are many more all the way from the complexity of a satellite communication system down to the simplicity of a car door opener. Siretta antennas operate in the range of 150 MHz through to 6 GHz.

This antenna technical parameter guide is not intended to explain how or why an antenna and its associated communication system works, just the technical points of the subject that need to be understood in order to be able to select and use an antenna.

It is arranged such that it assumes that the reader has no prior knowledge of antennas at the start of the document, but leads the reader through the subject, consistently building on topics started at the beginning of the antenna technical parameter guide.

In this way, the more knowledgeable reader can skip forward over topics that they are comfortable with, but that a reader who knows little about an antenna can read the full document to bring their knowledge up to a level where they will be comfortable about making the right selection choices for an antenna.

Intended Audience

The reader of this antenna technical parameter guide requires no prior knowledge of the purpose or operating principles of antennas. A basic knowledge of maths and physics is needed to understand the explanations, but not the summaries of the points covered. This antenna technical parameter guide's purpose is to educate the reader sufficiently enough to be able to confidently select and use an antenna in their application, and not replace books on antenna theory.

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Basic Theory and Parameters of Antennas

An antenna is a transducer which converts electrical power into radio frequency electromagnetic power and vice versa. All antennas can work in both directions of energy conversion which means they may work both as transmitters and receivers. Luckily, most antennas have a property called reciprocity. Reciprocity means that the transmit and receive properties of an antenna are identical. This in turn means that it is not necessary to have one antenna dedicated to transmitting and one to receiving.

Because of reciprocity, this antenna theory section will talk about an antenna radiating (transmitting) electromagnetic power to keep the explanation straightforward. But remember that everything works in the same way in the reverse direction for receiving.

Antennas are used in communication systems to eliminate wiring between both ends of the communication system. The use of an antenna does not necessarily eliminate wiring totally, as it is necessary to have a wire to connect the antenna to the product that it is being used with. Any such wiring, along with any connectors used, need to be considered as part of the antenna selection process for an application.

What is an electromagnetic wave? This is an electric field with an associated magnetic field (hence electromagnetic) that travels away from its source. This field will vary in synchronisation with the electrical signal applied to the transmitting antenna.

While an antenna has been defined as transmitting radio frequency electromagnetic power, no one says this in practice. Normally, this is just referred to as radio, or radio waves. Radio is just that part of the electromagnetic spectrum that we as humans use for what we describe as radio communication. But the electromagnetic spectrum is much larger and covers microwave, Infrared, visible light, ultraviolet light, X and Gamma rays. Because the electromagnetic spectrum includes visible light, it should come as no surprise that radio waves travel at the speed of light.

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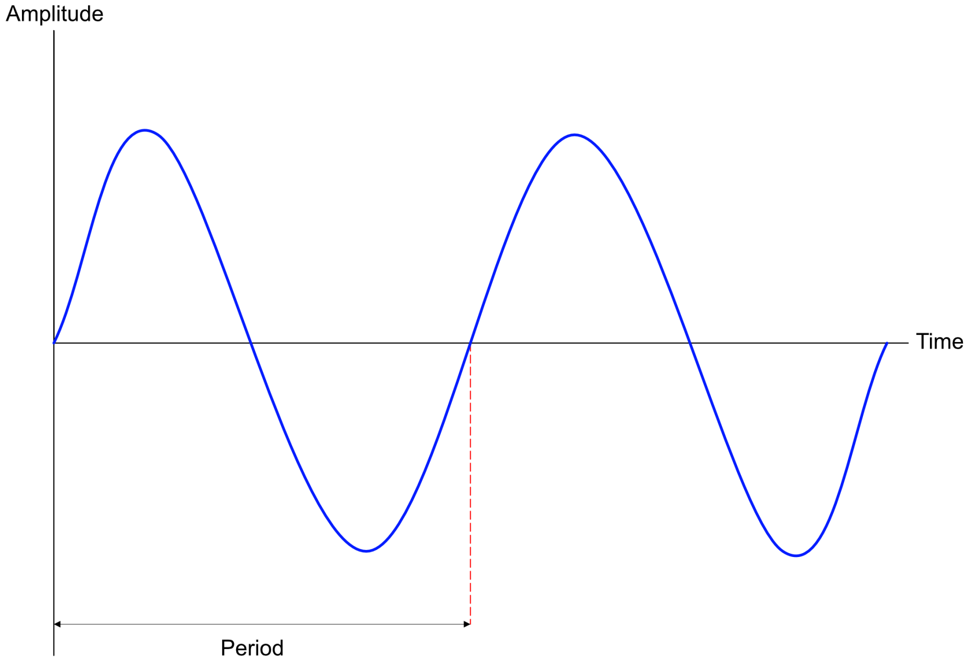
Frequency and Period

The most basic of all specifications of an antenna is its frequency of operation. This is the rate of repetition of the radio waves that it is designed to send. The output radio waveform of a radio system is unlikely to be a pure sine wave, but if it were, it would look like the figure below.

Figure 1. Frequency and period diagram



The time (in seconds) that it takes for a signal to repeat is called the period.

The number of times that a signal repeats in a second is called the frequency, the unit of measurement for which is the Hertz (Hz). 1 Hz = 1 cycle (or repetition)/second.

Therefore, if the period or frequency of a radio wave is known, the other can be derived using the formula:

$$Frequency\ (\mathrm{Hz}) = \frac{1}{Period\ (s)} \quad \text{or} \quad Period\ (s) = \frac{1}{Frequency\ (\mathrm{Hz})}$$

Wavelength

Wavelength has similarities to the period. While the period is a measurement in time, the wavelength of a radio signal is the measurement of the periods distance in meters. The SI symbol for wavelength is the Greek letter Lamba (λ).

Radio waves travel at the speed of light (SI symbol 'c') = 3.0 x 10^8 m/s

Therefore, the wavelength can be defined as:

$$Wavelength\ (\mathrm{m}) = Period\ (\mathrm{s}) * c\ (\mathrm{m\ /\ s}) \quad \text{or} \quad Wavelength\ (\mathrm{m}) = \frac{c\ (\mathrm{m\ /\ s})}{Frequency\ (Hz)}$$

The frequency is one of the most fundamental operating parameters of an antenna. Different wireless technologies work on different frequencies, so it is important that the right frequency antenna is used for the application.

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Impedance, VSWR, Return Loss and Reflected Power

Impedance is somewhat similar to the concept of resistance. The unit of measurement of resistance is the Ohm (Ω), which is defined as the resistance offered by an object when 1 Volt of potential difference is applied across it and 1 Ampere of current passes through it. Here resistance is denoted by R.

Impedance differs from resistance in that it takes into account energy stored in magnetic fields (by inductance) and electrostatic charge (by capacitors). These two energy stores are collectively called reactance and create a complex part to the measurement value due to the phase difference created between the voltage and current. Impedance is denoted by Z and is still measured in Ohms (Ω). Both inductors and capacitors change their characteristics based on the frequency of operation, so as a result the impedance will change with frequency.

So, the simple message is that, Resistance is frequency independent, and Impedance is frequency dependant.

As a reminder, an antenna is a transducer which converts electrical power into radio frequency electromagnetic power. The electrical power will come from an electrical circuit.

To maximise power transfer, the maximum power transfer theorem states that to obtain maximum external power from a source with a finite internal impedance, the impedance of the load must equal the impedance of the source as viewed from its output terminals. This is something that will need to be considered when selecting an antenna. So, when an antenna is connected into a circuit, it is the connector on the antenna that must be matched in impedance to the circuit that it is connected to, ie the mating connector.

It's not as obvious, but the impedance of the antenna will also need to be matched to its other interface, free space (impedance of 377 Ohms), to maximise the power transfer between the antenna and free air – but this is something that the antenna designer needs to concern themselves with, not the reader.

But why match impedance and not resistance? Because the antenna is working at specific frequencies and impedance is the frequency dependant measurement.

But what happens if the impedances are not matched? In this case some of the power will be reflected back to its source because a standing wave is created. A standing wave is the waveform created when an input waveform is altered by the addition of a reflected portion of that input waveform. The greater the mismatch, the greater the power reflection, and the poorer the performance of the antenna.

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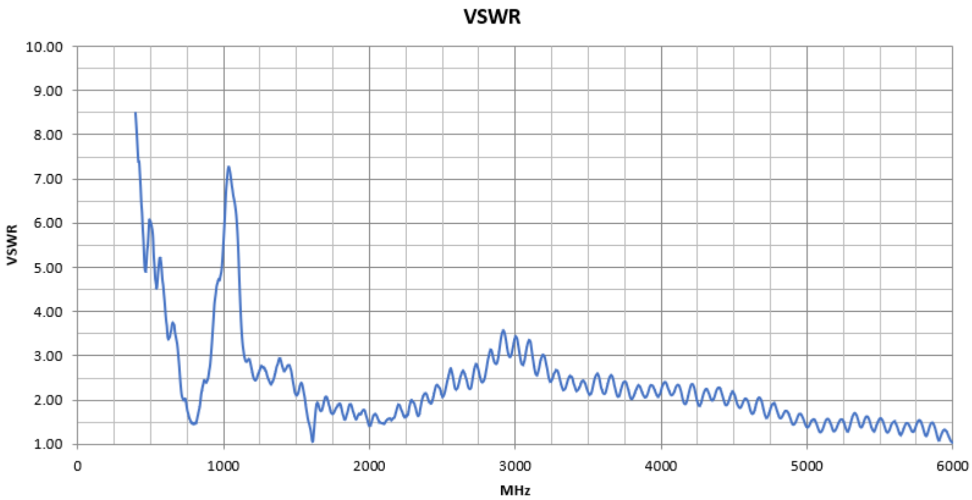
VSWR is the term used to describe how well the impedance is matched in an antenna. VSWR is the Voltage Standing Wave Ratio and is the ratio of the maximum voltage to minimum voltage in a standing wave. The ideal VSWR value will occur where the input and output impedances are perfectly matched. In this case the minimum and maximum voltages will be the same and the ratio will be one.

Because as we have seen the impedance can change with frequency, the VSWR is shown as a plot of VSWR ratio Vs frequency, as shown in the plot below taken from an antenna data sheet.

Figure 2. VSWR graph



In practice it is almost impossible to get a VSWR = 1. There is no right or wrong value of VSWR as this is one of several parameters which need to be taken together to work out if an antenna is suitable for an application. However, it should be noted that high values of VSWR will mean that that a large proportion of the signal could be reflected back, and this could cause damage to the circuit driving it (a reflected output becomes an input into the output circuitry).

Sometimes VSWR is shortened to just SWR, and sometimes it's known as reflected power. These are all the same.

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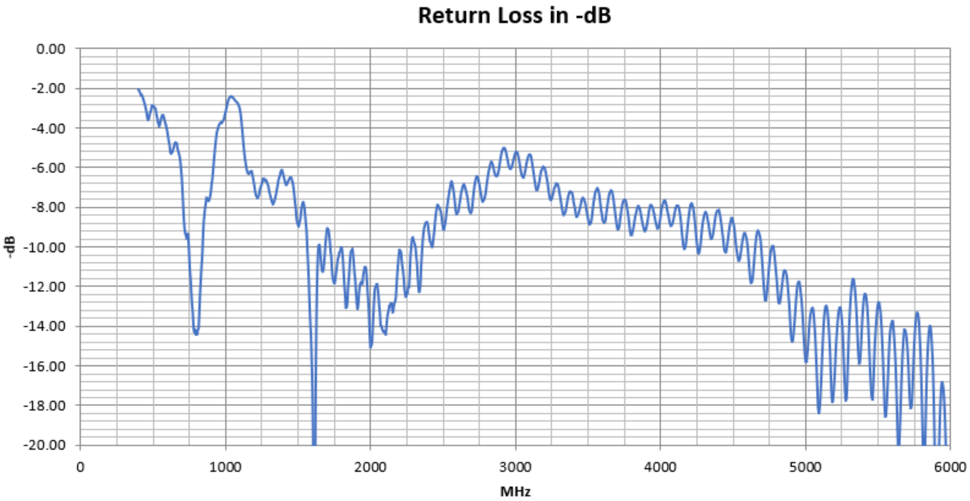
VSWR may be represented in different ways. VSWR is a ratio measurement of signal reflection. Return Loss measures the same signal loss in decibels. The decibel is a log measurement, so the same graph shown as Return Loss looks similar.

Figure 3. Return Loss graph



The table below shows equivalent VSWR and return loss values for different amounts of reflection while shielding the reader from the maths behind it.

Table 1. Equivalent VSWR and return loss values of reflected signal

Reflected Signal	VSWR	Return Loss
0% (perfect match)	1.000	∞ (-infinity) dB
5%	1.105	-26.021 dB
10%	1.222	-20.000 dB
15%	1.353	-16.478 dB
20%	1.500	-13.979 dB
25%	1.667	-12.041 dB
30%	1.857	-10.458 dB
35%	2.077	-9.119 dB
40%	2.333	-7.958 dB
45%	2.636	-6.936 dB
50%	3.000	-6.021 dB
60%	4.000	-4.437 dB
70%	5.667	-3.098 dB
80%	9.000	-1.938 dB
90%	19.000	-0.915 dB
100 % (perfect mismatch)	∞ (infinity)	-0.000 dB

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Radiation Efficiency

In the preceding section we talked about impedance matching and VSWR as being important to transfer maximum power to and from the antenna. Now we need to discuss radiation efficiency which is the ratio of the total power radiated by the antenna to the net power accepted by the antenna at its connector. This measurement is independent of impedance matching or polarization mismatch.

An antenna with high efficiency will radiate a high proportion of the electrical power applied to it, an antenna with poor efficiency will do this poorly, instead converting some of the electrical power into other energy forms such as heat.

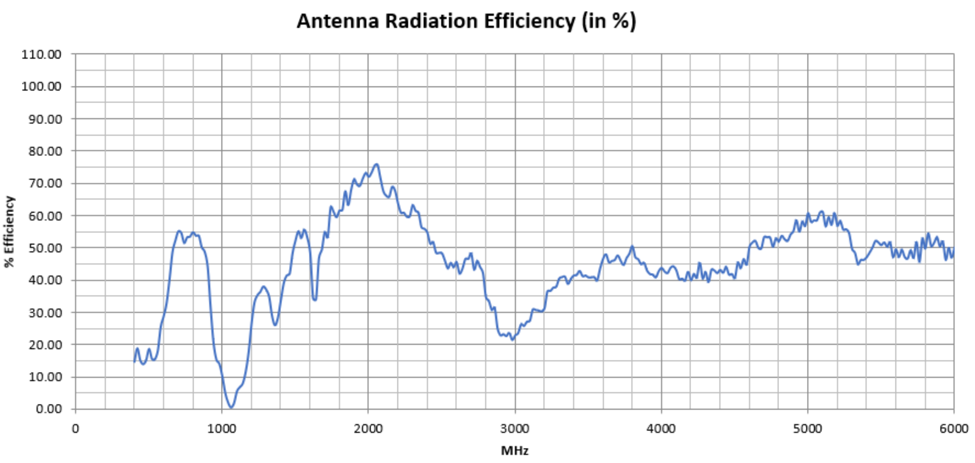
The equation that defines the radiation efficiency (εR) is:

$$\varepsilon R = \frac{P\text{radiated}}{P\text{input}}$$

Since this is a ratio, the result will always be a number between 0 and 1 (since you can never output more than is put into the antenna). However, it is rare that the antenna radiation efficiency is presented in this way. Usually, it is presented as a percentage where a ratio of 0 = 0% and a ratio of 1 = 100% efficiency. Sometimes it may also be presented in decibels (dB) where an efficiency of 0.5 (50%) is -3 dB and an efficiency of 0.1 (10%) is -10 dB.

Siretta chooses to use percentage as the units of measurement of Antenna Radiation Efficiency, as seen in the plot below of our sample antenna.

Figure 4. Antenna Radiation Efficiency graph



Polarization

Analogous to voltage and current describing an electrical signal and its properties, an electric and a magnetic field describe an electromagnetic radio wave. Polarization describes the relationship of these two components of the radio wave as they travel through space.

There are three types of polarization, each with two subtypes:

» Linear (vertical & horizontal)

» Circular (left hand & right hand)

» Elliptical (left hand and right hand)

When describing polarization, the electric signal is designated 'x', the magnetic signal 'y' and the direction of travel 'z'. In the case of a transmitting antenna, z is the line starting at the antenna and ending at the point of observation of the signal. The frequency of x and y will be equal and travelling in the direction z.

Linear Polarization

A linearly polarised radio wave has its electric and magnetic fields perpendicular to each other as they propagate. They may be at any angle relative to z, but normally they are described as vertical or horizontal. When viewed along the z axis at a fixed distance looking back to the wave source (the antenna), the electric and magnetic fields waveforms amplitude will go up and down at the waveforms frequency in the case of vertical polarisation and left and right in the case of horizontal polarisation.

Figure 5. Horizontal polarization

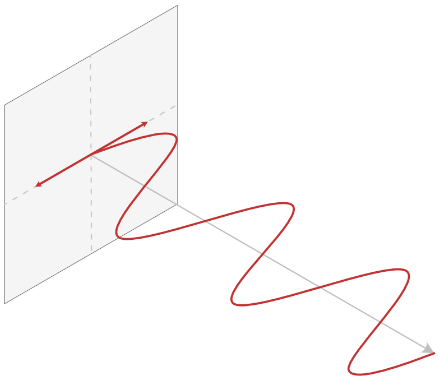
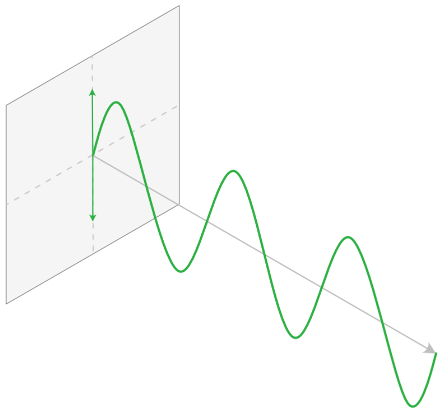


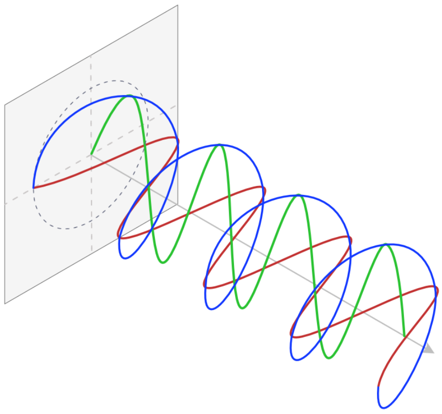
Figure 6. Vertical polarization



Circular Polarization

A circular polarised waveform has its electric and magnetic components rotated relative to each other by 90 degrees (orthogonal), and with a 90 degree phase added in. Visually, this is like the horizontal and vertical polarisation diagrams above added to each other and with one component phase shifted along the z axis by 90 degrees.

Figure 7. Right hand circular polarization



With circular polarization, if you look back down the z axis towards the antenna, the electric and magnetic components are no longer at the same amplitude at any point in time because of the 90-degree phase shift. One will follow the x axis and the other the y axis. If the peak amplitude of the electric wave matches the peak amplitude of the magnetic wave, and the x-y coordinates at a fixed distance along the z axis are plotted in time, it will trace out a circle, hence the name. Depending on the phase shift being +90 or -90 degrees, the point tracing the circle will appear to move either clockwise (left hand circular polarization) or counter-clockwise (right hand circular polarization).

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Elliptical Polarization

Elliptical polarization is the same as circular polarization with the exception that the peak amplitudes of the electric and magnetic waves are no longer matched. This means when the x-y coordinates are plotted, an ellipse is created rather than a circle.

Why Polarization is Important

Any radio system uses two antennas. To transfer the maximum power between the antennas they need to work in the same way. A linear polarised vertical antenna will transfer maximum power to a linear polarized vertical antenna as their polarizations are aligned. However, if one of those antennas is rotated by 90 degrees such that the polarization of the antennas is orthogonal to each other, then no power is transferred.

Vertical polarization is used in mobile communications as they are not affected by reflections from the earths surface. Horizontal polarization has more limited uses. It is used in HF communications where the wire antenna hung between two poles naturally forms a horizontal polarisation, and in television broadcast by the main transmitters. Smaller television relays use vertical polarisation to avoid interference.

In communication between a satellite and the ground, circular polarisation is used as this is independent of the antenna rotation. It just needs to point upwards. Circular polarisation also has the useful property where it will change from left to right-handed circular polarisation and vice versa when reflected. For this reason, GNSS systems have been standardised on RHCP. A signal that has been reflected once (or an odd number of times) will not be seen by the GNSS receiver, reducing interfering signals and improving the positional accuracy.

Radiation Pattern and Gain

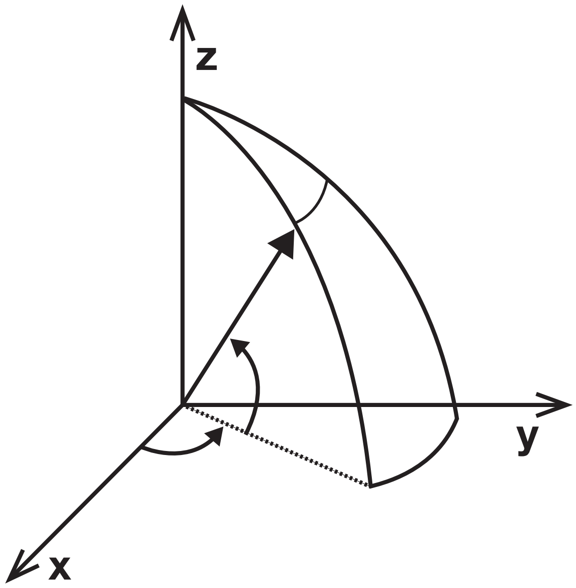
An antennas radiation pattern and gain are both ways of describing how symmetrically the antenna radiates or absorbs electromagnetic radiation (depending on if it is transmitting or receiving). These parameters are typically provided at the different frequencies at which an antenna is designed to operate as they can and will change with frequency.

The reference for radiation pattern and gain is an isotropic radiator. An isotropic radiator is a hypothetical antenna which is the source of electromagnetic waves which radiate at the same density in all directions. Since it radiates uniformly in all directions, it has no directivity. An isotropic receiver is the opposite of an isotropic radiator. An isotropic receiver placed at a fixed distance from an isotropic transmitter will output the same electrical signal no matter where it is placed relative to the transmitter – as long as the distance is fixed.

Gain is a way of describing in numbers how an antenna is deviating from an isotropic radiator or receiver and the radiation pattern is a way of visualising this.

Antennas radiate (and receive) in all 3 dimensions, but it can be difficult to visualise and characterise a three-dimensional space. So, we break this down into 3 orthogonal planes which we call x, y and z on which the power density is plotted. The x and y planes are the azimuthal planes and z is the elevation plane.

Figure 8. Plotting orthogonal planes



Because an isotropic radiator radiates uniformly in all directions, the power density plot in any plane (x, y or z) will all be the same. For any given power density, the plotted power from an isotropic transmitter will be a perfect sphere. The reference point for measuring gain is the power density plot of the isotropic transmitter. Gain is measured using the logarithmic scale where 0 dBi represents the same power density as that created by an isotropic transmitter, and +3 dBi a gain of about 100% (doubling). The units of measurement are dBi which is a ratio and stands for 'decibel relative to isotrope'. For those unsure of what the logarithmic scale is, common dBi gains and their corresponding ratio are listed here:

Table 2. Positive dBi gains

Gain	Ratio
0 dBi	1.000
+1 dBi	1.259
+2 dBi	1.585
+3 dBi	1.995
+4 dBi	2.512
+5 dBi	3.162
+10 dBi	10
+15 dBi	31.62
+20 dBi	100

Table 3. Negative dBi gains

Gain	Ratio
0 dBi	1.000
-1 dBi	0.794
-2 dBi	0.631
-3 dBi	0.501
-4 dBi	0.398
-5 dBi	0.316
-10 dBi	0.1
-15 dBi	0.032
-20 dBi	0.01

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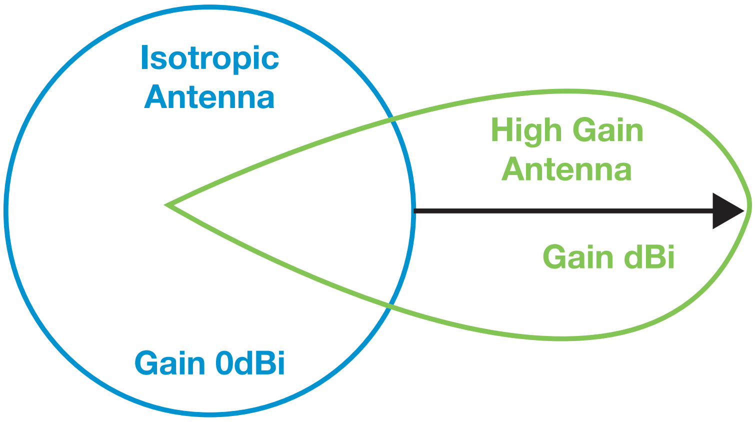
There are three types of antenna radiation pattern. The reference isotropic pattern, omnidirectional and directional. An omnidirectional antenna produces a field of approximately equal intensity in all directions along the azimuthal plane (but could vary in power on the elevation plane). A directional antenna radiates primarily in one direction.

Note that gain just indicates the direction in which the power is focussed. It does not mean that an antenna is necessarily better – that depends on the application. A gain in power in one direction will result in a loss of power in other directions. This is seen most readily in a theoretical radiation pattern plot in one plane of a directional antenna, as shown in the figure below.

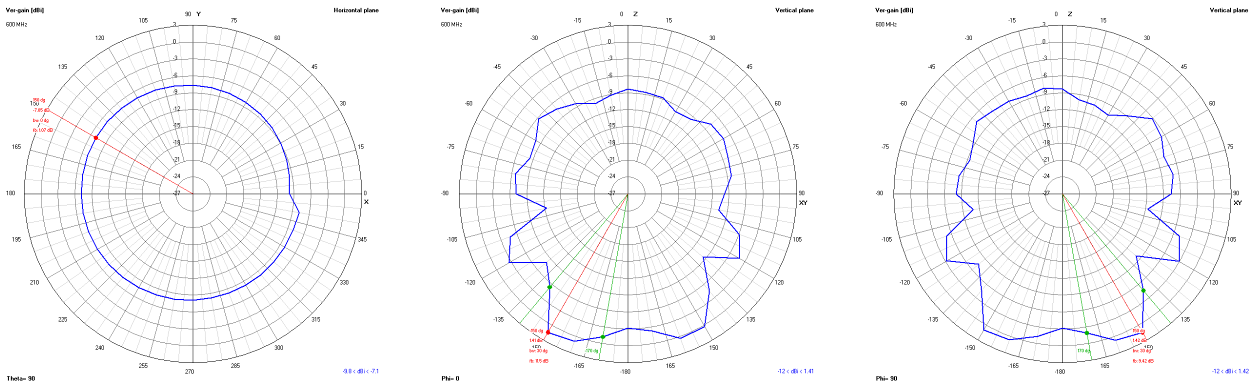
Figure 9. High gain antenna



The below figures are the 600 MHz radiation pattern plots from our sample antenna. In the xy plane the plot is circular, so this antenna can be described as omnidirectional in this plane. All these plots are on the same scale (but always read the units of measurement on the axes as this should not be assumed).

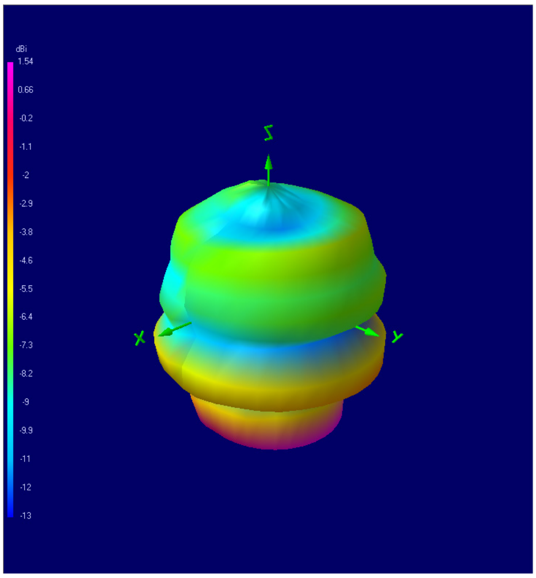
Figure 10. 2D radiation plots @ 600 MHz

600 MHz XY | 600 MHz XZ | 600 MHz YZ



These plots are 'cuts' from the three-dimensional radiation plot, as shown in the figure below:

Figure 11. 3D radiation plot @ 600 MHz



Band and Bandwidths

In radio applications, frequencies are grouped together into bands. This is done in a regulatory framework to ensure that different applications using the radio spectrum do not interfere with each other. A band will contain a range of frequencies, and the bandwidth is the width of the spectrum between the highest and lowest frequencies in a band. Bands are the usually subdivided into channels. These bands and channels are harmonised in their definition worldwide, but authorisation to be able to use them is done by the national regulatory bodies in each country. What is permitted in one country isn't always permitted in another.

For instance, Wi-Fi using what is referred to as the 2.4G band uses frequencies in the range of 2401 through 2495 MHz. This is broken down into 14 numbered channels. So, any WiFi device using the 2.4G band is using one of these numbered channels. Channels 1 through 11 are safe to use anywhere in the world, while channels 12 through 14 can only be used in specific parts of the world. To make life even more challenging for a designer of products using WiFi, different countries also have limits to the maximum power that can be used to transmit a WiFi signal. Therefore, you are required to know what country the device is being operated in to know what frequencies and what power levels may be used.

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Near Field and Far Field

All the theory explained so far assumes that the antenna is working in what is described the Far Field. The area close to the antenna is described as the Near Field. Things happen differently in the Near Field and the simple explanation is that the antenna is not going to behave as its datasheet describes in the Near Field, so stay in the Far Field.

To be using the Far Field, an antenna must meet all of the following criteria, where D is the maximum dimension of the antenna, λ is the wavelength and R the distance from the antenna (all dimensions are in meters):

$$R > \frac{2D^2}{\lambda} \qquad R > 10D \qquad R > 10\lambda$$

Take a 2.4 GHz wireless application using a Siretta Delta 6A antenna as an example. 2.4 GHz WiFi has a wavelength of 0.125m and the effective length of the antenna is 166 mm (deduced from the drawing on the data sheet). The three equations resolve to:

$$R > 0.44m \qquad R > 1.66m \qquad R > 1.25m$$

So, if the WiFi client is at least 1.66 m away from the WiFi access point, everything should work well. 1.66 m is not a drop-dead value - the antenna will most certainly work closer to the access point as well – it's likely that the overall efficiency will be reduced.

Antenna Selection Checklist

This is a list of what needs to be thought about, and in the order that it needs to be thought about to decide the operational parameters to be looked for in an antenna. Some parts of the checklist like core frequencies are "must haves". Other parts like some other frequencies or connectors that could be changed with adapters are "nice to haves". Knowing the wireless standard to be used will answer or help to answer many of the questions on this checklist.

Determine Frequencies and Transmit Power Used

All the radio spectrum is regulated so that all users of the radio spectrum can co-exist with each other. The application will need to conform with all relevant radio standards applicable in the country of use. This includes the frequency bands used and the transmit power levels.

The most common uses of the radio spectrum are cellular (GSM / UMTS / LTE), WiFi, Bluetooth, GNSS and ISM. A more extensive list of uses and the frequencies used are listed in Appendix A. In all these applications the frequency bands used and the transmit power allowed will be specified.

To decide what frequency bands that the antenna needs to work with, first decide what is supported by the equipment that it is being attached to. Then adjust by removing bands not allowed in the country of use. This leaves the frequency bands that the antenna must support.

The total output power level is determined by the electrical circuit that the antenna is connected to. However, it is not only the designer of this circuit who must ensure that the output power level follows national radio regulations. A high gain antenna could mean that radio regulations are broken in the direction of high gain.

Determine Where the Endpoints Are

Are both ends of the radio link fixed? If so, a directional antenna on both ends of the radio link pointed at each other will be the best solution. Any end that is moving or could be placed in an unknown orientation with respect to the other end of the radio link should use an omnidirectional antenna as these types of antenna work well in any orientation. An omnidirectional antenna will not have high gain.

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Determine Placement

Consider where the antenna is to be placed. Inside an equipment box? Outside? Will it be required to be placed some distance from the equipment in order to get a better signal, such as on a pole or roof? The answers to these questions will help determine the antenna form factor, environmental rating and cable lengths required.

Determine Form Factor

Siretta groups mechanically similar antennas into product ranges. The product range name identifies the style of antenna:

Alpha: An Alpha antenna is an **A**dhesive antenna. The key point is that it is stuck to a flat surface. This means that it is a low-profile antenna which is unobtrusive and more discrete. This range has a cable with connector which means that they can be placed away from the equipment that they are being used with.

Delta: A Delta antenna is designed to **D**irectly attach to a product, which is the mounting point. Having no cable means that there are no cable losses and performance could therefore be better than that of a cabled antenna. But remember that a cabled antenna could be placed where there is better reception, overcoming any losses in the cable. Using our magnetic bases, a direct attach antenna can be moved away from the equipment and better placed to receive/transmit the signal.

Echo: An Echo antenna is designed to be **E**mbedded in a box along with the equipment that it is to be used with. They are designed to either be directly soldered to a PCB or attached via a short cable with small press fit connectors such as IPEX.

Mike: A Mike antenna has a **M**agnetic mounting, and unless used for GNSS where they lie flat to look at the sky, stand proud. This range has a cable with connector which means that they can be placed away from the equipment that they are being used with. Having a magnetic base means that the placement may be easily adjusted once installed. However, this also means that they can be interfered with more easily.

Tango: A Tango antenna is a **T**hrough-hole antenna. This makes them good for box or vehicle mounting. Once fitted, it will be difficult to remove unless access to both sides of the mounting plate is obtained. This range has a cable with connector.

Oscar: An Oscar antenna is an **O**utside antenna designed to be mounted on a wall or pole. Consequently, they are often used where getting good reception is difficult. Many antennas in this range are high gain, generally provided with weatherproof N-type connectors and used with a separate extension cable to reach the equipment that it is being used with.

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Determine Environmental

There are two general environmental conditions to consider, which are temperature and water.

The temperature of an antenna will not be the same as the air temperature as it depends on where the antenna is mounted. An antenna mounted in direct sunlight will get hotter than an antenna in the shade even if the air temperature is the same because of the direct radiative heating effect of the sun. An antenna mounted in direct sunlight in still air will get hotter than an antenna mounted in direct sunlight in a breeze.

Taking the temperature of antenna beyond its data sheet specifications is not likely to have much affect on its performance as an antenna. The temperature will influence the materials used in the construction of the antenna. This usually means that plastics lose rigidity and deform (at elevated temperatures) or could become brittle and shatter if stuck at low temperatures.

For water resistance, antennas that are designed to work in the rain will have an IP rating assigned to them. The IP rating is a standardised rating that describes the water protection of a product. For protection from the rain, IP65 is sufficient, although IP66 or IP67 could also be used. Sometimes customers request a greater IP rating than is needed. To pass IP66, the antenna must withstand water at high pressure from a 12.5 mm jet. This is more powerful than a monsoon rain. At IP67 the product can be submerged. Radio does not travel well through water, so it is unlikely that an antenna would work as an antenna anyway if submerged. But if it were used on a telemetry site that could be flooded and submerged, an IP67 antenna would continue to work after the floods had receded rather than become waterlogged and fail.

So, in summary, IP65 is sufficient for the antenna is to be used outside.

Determine Impedance

Check the impedance requirement of the product that the antenna is to be used with. The antenna chosen will need to match this.

The impedance needed will probably be 50 Ohms. The only antennas that Siretta are aware of that are not 50 Ohms are FM radio antennas which could be 75 or 300 Ohms and Television/DVB antennas which are 75 Ohm.

Remember that the impedance needed is not just the antenna but also any extension cable and connectors. Take care, standard video cable is 75 Ohm and can be easily confused with 50 Ohm cable.

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Determine Connectors

Most equipment requiring an antenna will have an SMA connector on it. This is not a weatherproof connector but does contain a small rubber washer to prevent moisture build up. Equipment SMA connectors are always female type, meaning that the threads are on the outside of the antenna connector. In most cases this also means that the rf signal pin in the centre of the connector is also female. But beware! There are also female connectors that are what is called ‘Reverse Polarity’. This means that they are threaded on the outside, but the centre pin is male.

There is a similar explanation for male connectors. An SMA male connector has the threads on the inside of the barrel and a male rf signal pin. The reverse polarity version of this connector still has the threads on the inside of the barrel but has a female pin.

Table 4. Determine connectors

	Straight (SMA)	Reverse Polarity (RPSMA)
Male		
Female		

Reverse polarity SMA connectors have become standard for WiFi applications. They were originally used to prevent consumers from changing the antennas on their access points to high gain types that would allow the output power to exceed that allowed in national regulations.

If the antenna connector can be directly matched with the connector on the equipment that it is to be used with, then this is the best solution. However, this is not always possible. An antenna designed to be used outside will have a weatherproof connector for instance. If this means that an extension cable is used, the best solution will be to use an extension cable with the right connectors on each end. Avoid the use of cables connected in series and gender changing/connector style changing adapters if possible. Every connection will introduce a small impedance discontinuity which will create return loss. Use of adapters should be considered a temporary solution until the correct cable is obtained.

Ensure that the maximum frequency response of any cable used is greater than the frequencies used in the application. While most SMA connectors have a frequency response of 6 GHz or more, which will be suitable for most antennas available from Siretta, there are SMA connectors on the market that have frequency responses as low as 1 GHz which would only be suitable for ISM band operation.

Determine Cable

Sometimes there will be cases where the cable supplied with the antenna is not long enough, or in the case of the Oscar antennas intended for outdoor use, are not supplied with a connection cable. In this case a connection cable will be needed.

Like the connectors, the cable impedance needs to be matched with the application. Beware 75 Ohm video cables, use 50 Ohm impedance for wireless antennas.

Always try and keep any cable used as short as possible and use a good quality cable. Using a longer cable may well allow the antenna to be positioned somewhere where it can receive a stronger signal, but this needs to be balanced against the losses in the cable. There comes a point where signal advantage by better antenna placement is cancelled by the losses in the cable. For cellular applications, Siretta has the SNYPER cellular signal strength tester that allows for field measurements of received signal strength to be made that allows an installer to optimise antenna placement for best signal strength.

Cabling is explained very well by our application note:
"It's just a piece of cable, why should I care?".

Also consider moving the equipment being used closer to the antenna. Ethernet or RS232 cables can have long cable lengths without affecting the application that they are being used with.

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Understanding the Datasheet

All Siretta antenna datasheets showing the Antenna Test Lab verified logo in their footer have been independently tested by the Antenna Test Lab: https://antennatestlab.com/.

These data sheets present the test results provided by the Antenna Test Lab in the same way.

Figure 12. Antenna Test Lab verified logo

To understand how the antenna functions at the frequencies of interest, VSWR or return loss, radiation efficiency and the radiation plots need to be considered together. Considering anything less than all of these operational parameters will not give a true picture of the antenna performance.

VSWR / Return Loss is the measurement of power transferred into / out of the antenna at any given frequency

Radiation Efficiency is a measurement of the efficiency of the power transferred into / out of the antenna into / from radio waves at any given frequency

Radiation plots show the relative gain of the antenna to points in a sphere around it, ie how even its radiation pattern is.

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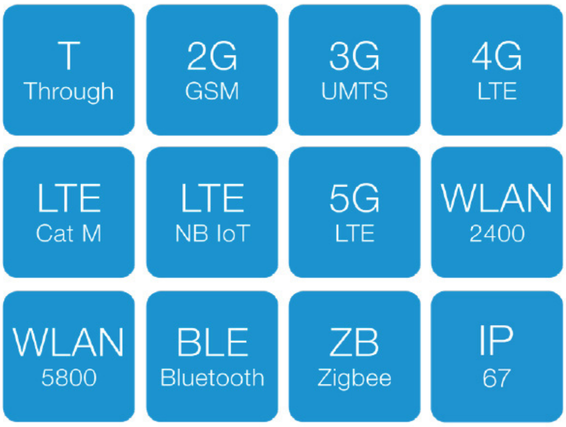
Cover Page

The first page of the data sheet always shows a picture of the product along with a general description and list of key features. At the bottom right of the data sheet are tiles that showcase the features of the antenna. These tiles match the selection criteria used by the antenna selector tool on the Siretta website at:
https://www.siretta.com/products/antennas/antenna-selector/

They give a quick visual overview of the main applications of the antenna. Where tiles are shown with a light blue background, these are applications that the antenna may be used with but may only cover specific bands. More user interpretation of the frequency response of the antenna to the frequencies used by the target application is needed.

Figure 13. Antenna features



Environmental, Electrical and Mechanical Specifications

These are the non-radio specifications found on the second page of the data sheet.

Having determined the features required of the antenna by working through the checklist, the non-radio parts of the antenna specification can be compared requirements to narrow down the selection. Unless the application is unusual, it is unlikely that many antennas will be disregarded at this part of the selection process.

Ground Planes

One feature to look out for is that some antennas, because of their construction, require a ground plane beneath them to achieve their data sheet specifications. This is a possibility for an antenna in the Mike or Tango ranges. A ground plane means that the antenna needs to be placed on a surface that will reflect the radio signals.

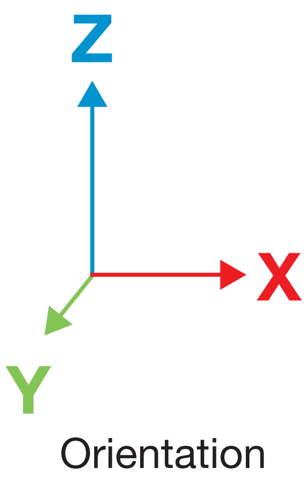
Despite its name, there is no requirement for the ground plane to be electrically grounded. The data sheet often specifies the size needed, which should be read as a minimum size. If a ground plane is needed but not specified, then it should extend at least ¼ of the antenna's wavelength from the antenna in all directions on the plane on which the antenna is mounted.

The material for the ground plane should be electrically conductive. A metal surface such as iron or aluminium is the usual choice. It should have a smooth, flat surface so that the radio waves are not scattered randomly from it. With time many metals corrode and can end up with a pitted surface. In such circumstances it is usual to paint the ground plane to protect it.

Orientation Diagram

The orientation diagram is particularly important to understand how to get the best from the antenna. This is placed beside the drawing of the antenna and shows how the antennas X, Y & Z planes are orientated. The Z plane always points up to the sky. A vertically linearly polarized antenna that has been put on its side becomes a horizontally linearly polarized antenna. The radiation plots shown later in the data sheet are referenced to this orientation diagram.

Figure 14. Antenna orientation



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Radio Aspects

The antenna parameters that directly relate to antenna performance are Return Loss, VSWR and Radiation Efficiency. The 2D and 3D Radiation plots can also have an impact, but for most use cases the antenna is likely to be used in the omnidirectional in the XY plane where direction is not going to impact the performance. The 3D radiation test results are used as the source measurements to produce the Radiation Efficiency plot.

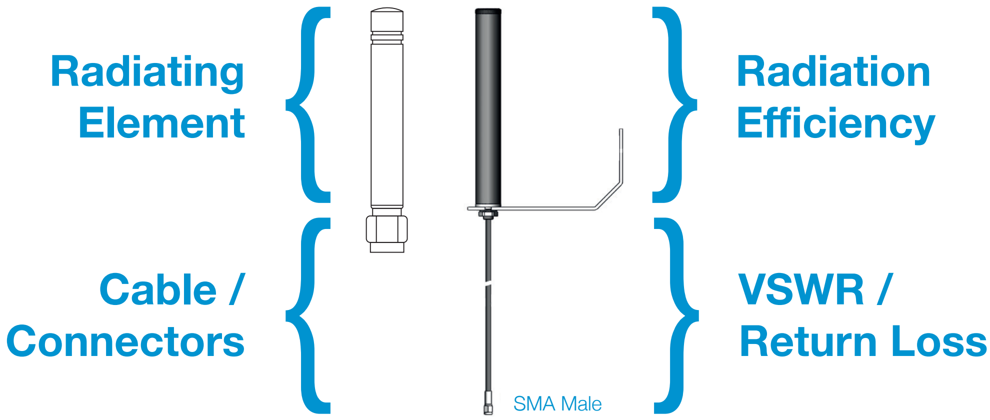
Return Loss and VSWR are different ways of specifying how much power is transferred into an antenna that is transmitting / radiating.

Radiation Efficiency is specifying how efficient the antenna is at converting the power that it receives into radio energy.

Both need to be looked at in conjunction with each other at the frequencies which the antenna is going to be used at to determine if it is suitable. There is no black and white pass mark to determine suitability. What happens as the antenna performance deviates from the optimum is that the effective communication range is reduced.

Because of reciprocity, an antenna will have the same characteristics when it is used to transmit radio waves as when it receives radio waves.

Figure 15. Antenna performance parameters



Return Loss

All antenna data sheets have a return loss plot covering all frequencies between 400 MHz and 6 GHz (exception: GNSS antennas as they are designed to receive only) on a scale of 0 to -20 dB which allows easy comparison between models. Return loss is measuring how effectively power is transferred into the antenna. Because this this is measuring loss, the smaller the loss the better the transmit performance. An ideal antenna will have a small return loss. Remember that dB measurements are logarithmic.

20 dB represents 10% signal loss

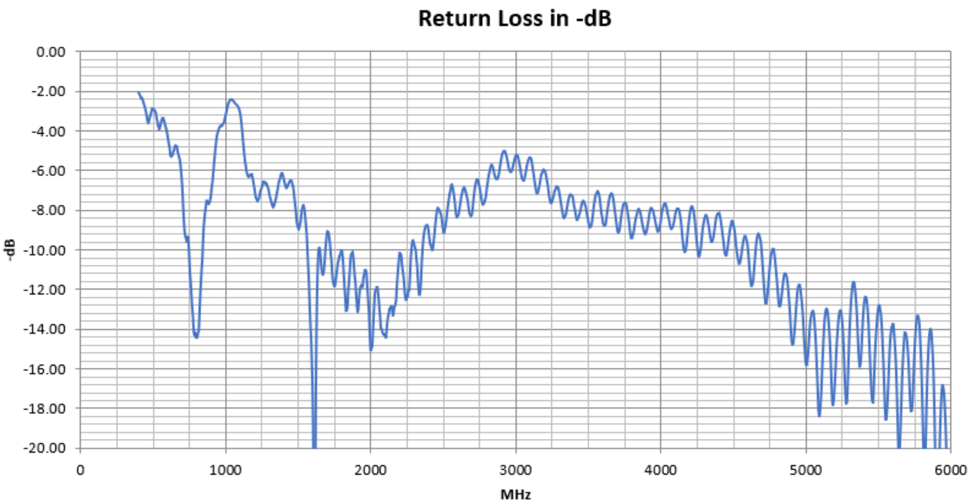
12 dB represents 25% signal loss

6 dB represents 50% signal loss

Any frequency that manages to hit the bottom of the graph (-20 dB) clearly has the very best return loss performance. But an antenna needs to be judged on its overall performance, not just return loss.

Note that if the antenna includes cable (such as the Mike family), that the Return Loss includes the losses that the cable introduces. The tested cable length is always specified. Because of this, a direct attach antenna (such as the Delta family) may appear to have a better return loss than a cabled antenna.

Figure 16. Return Loss



VSWR

VSWR is an alternative way of expressing return loss in that it is measuring how effectively power is transferred into the antenna. However, instead of the measurement being a plot of dB loss vs frequency, this is a plot of loss ratio vs frequency. Because the Return Loss and VSWR graphs are presenting the same information in different ways, the reader should use whichever measurement method that they are most comfortable reading.

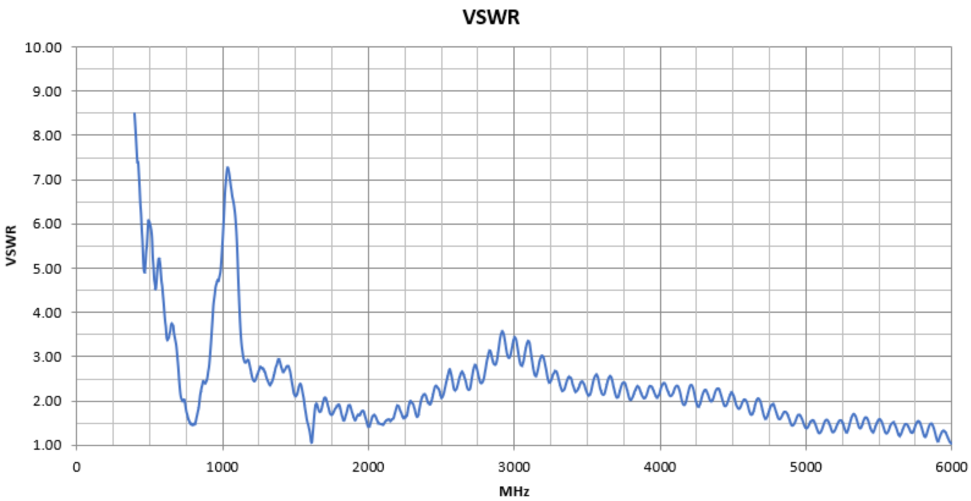
1.2 represents 10% signal loss

1.7 represents 25% signal loss

3.0 represents 50% signal loss

Here a measurement result of one is perfect performance from the antenna.

Figure 17. VSWR



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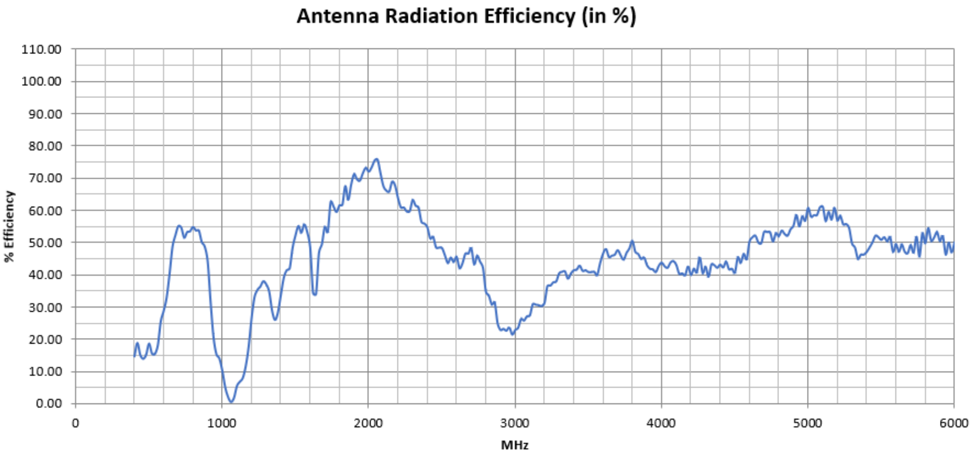
Radiation Efficiency

All antenna data sheets have a radiation efficiency plot covering all frequencies between 400 MHz and 6 GHz (exception: GNSS antennas as they are designed to receive only) on a scale of 0 to 110% which allows easy comparison between models. Radiation efficiency is the efficiency at which the antenna converts the power transferred to it into radio waves. Here, 100% efficiency is the best antenna performance.

Note that if the antenna includes cable (such as the Mike family), that the Radiation Efficiency includes any reduction in efficiency that the cable introduces. The tested cable length is always specified. Because of this, a direct attach antenna (such as the Delta family) may appear to have a better radiation efficiency than a cabled antenna.

The radiation efficiency plot is generated from the spherical integration of the 3D radiation plots.

Figure 18. Radiation efficiency



LTE/5G Band Coverage

4G LTE and 5R NG cellular have many different bands of operation compared with 2G GSM and 3G UMTS cellular systems. To add to the complexity, NBIoT uses a subset of the available LTE frequency bands. To help the user make sense of all these bands and what the antenna is capable of, Siretta has summarised this information into a table that includes the measured performance of the antenna on all the different bands, together with a traffic light system to show the antennas suitability at any band of interest. 2G GSM and 3G UMTS use the same band numbers as 4G LTE.

Table 5. LTE/5G Band Coverage

LTE, CAT-M/5G Bands	NB-IoT Band	Regional Coverage	Uplink	Downlink	Avg Efficieny % over band	Max VSWR over Band
1/n1	B1	Europe / Asia	1920-1980 MHz	2110-2170 MHz	70.81 / 67.15 ●	1.78 / 1.60
2/n2	B2	North America/Latin America/Caribbean	1850-1910 MHz	1930-1990 MHz	67.85 / 71.04 ●	1.91 / 1.78
3/n3	B3	Europe/Africa/Asia/Oceania	1710-1785 MHz	1805-1880 MHz	58.79 / 64.36 ●	2.07 / 1.91
4	B4	North America/Latin America/Caribbean	1710-1755 MHz	2110-2155 MHz	57.94 / 67.04 ●	2.07 / 1.59
5/n5	B5	Country Specific	824-849 MHz	869-894 MHz	52.51 / 47.71 ●	2.13 / 2.47
7/n7		Latin America/Europe/Asia +	2500-2570 MHz	2620-2690 MHz	45.47 / 45.39 ●	2.71 / 2.66

Table Explanation

LTE, CAT-M/5G Bands: LTE band is the band number. 5G NR bands are prefixed with ‘n’ as specified by 3GPP. Where 5G NR overlaps with 4G LTE, they use the same band number.

NB-IoT Band: Although NB-IoT is part of the LTE specification, it does not use all the bands used by LTE. Those used are listed.

Regional Coverage: This shows where the bands are typically used. However, many are country specific rather than used through a region. The user is advised that this is a general statement and that band use in specific countries (and specific networks) be checked before use.

Uplink: The range of frequencies used for the uplink part of the band.

Downlink: The range of frequencies used by the downlink part of the band.

Average Efficiency % over band: The values provided here are taken from the Radiation Efficiency plot and are the average values for the uplink and downlink respectively. A traffic light system gives a visual indication of how Siretta perceives the antennas suitability for that band of operation, taking into account the Average Efficiency and VSWR.

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Max VSWR over band: Maximum VSWR value for the uplink/downlink over the frequency band.

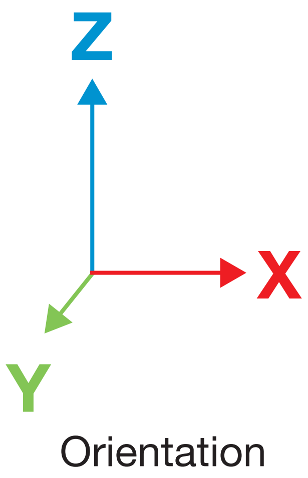
The radiation efficiency and VSWR values presented in the table are taken from the data used to produce the radiation efficiency and VSWR plots.

Radiation Plots

The radiation plots shown cover the most operational frequencies of the antenna. Note that unlike the Return Loss, VSWR and Radiation Efficiency plots that use common scaling allowing different data sheets to be directly compared, the radiation plots use different scales for the radiation patterns. Even within a datasheet, different scales can be used for plots at different frequencies to best show the pattern. All plots of the same frequency are displayed with the same scale and are in reference to the XYZ orientation of the antenna that is shown in the data sheet.

Two different visualisations of the radiation plots are provided, 2D and 3D.

Figure 19. Antenna orientation



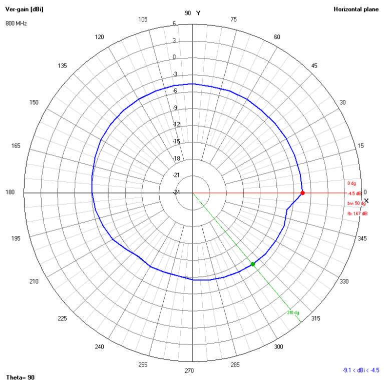
2D Radiation Plots

Plots in the XY, XZ and YZ planes are provided. These are different 'cuts' of the 3D antenna radiation pattern and show the relative energy dissipated, along with the direction. The XY plane is looking down on top of the antenna and as the cut is at the chart mid-point does not necessarily mean it shows the maximum values. The 3D plot gives a better overview of the radiated energy.

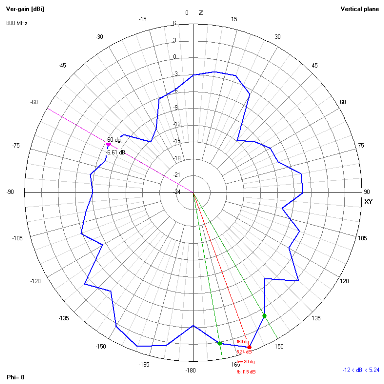
Most small antennas are designed to be omnidirectional. In practice it is not easy to achieve across a broad range of frequencies .

Figure 20. 2D radiation plots @ 800 MHz

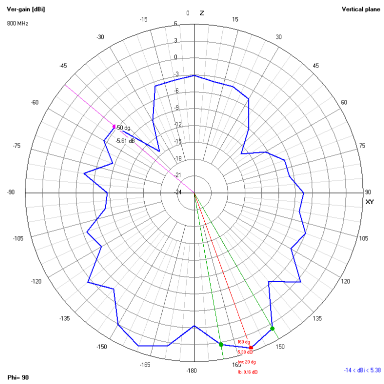
800 MHz XY



800 MHz XZ



800 MHz YZ

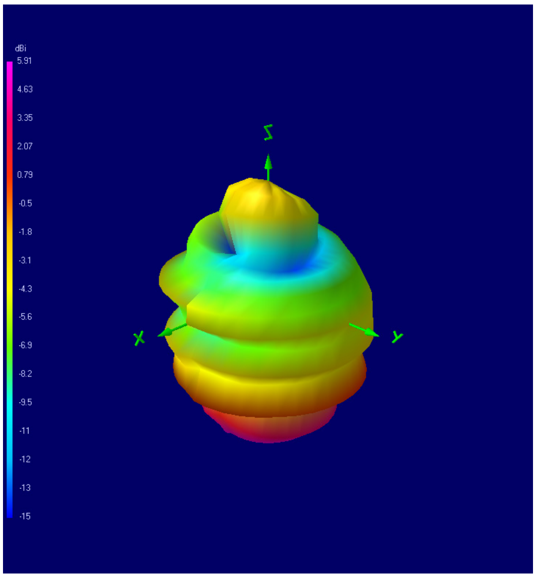


3D Radiation Plots

Here the true shape of the radiation pattern is shown. While detail can be inspected in the 2D radiation patterns, by slicing the radiation pattern into 3 planes, distortions and unexpected patterns are missed. The 3D plots show the true shape of the radiation field.

It is the integration of the 3D plots that are used to generate the radiation efficiency plot.

Figure 21. 3D radiation plots @ 800 MHz



Antenna Installation

The key points to consider with any antenna installation are cable type and length, polarisation, and line of sight between the antennas. Different applications and technologies require these key points to be dealt with in separate ways.

Siretta has a separate application note about cables:
"It's just a piece of cable, why should I care?".

The reader should read this application note for the full explanation, but the general guidance is to both keep the cable as short as possible and to use low loss cables in order to maximise the antenna performance. The general rule of cables is "does using this cable allow me to place the antenna in such a position that I gain more signal by the better antenna placement than the loss introduced by the cable?".

Adapters for gender changing or connector style changing will always introduce losses and such use is to be frowned on. Their only benefit is to get a system up and running quickly if the right components are not available, but they should always be considered a temporary solution and replaced as soon as possible.

GNSS (GPS, Galileo, GLONASS, BeiDou and QZSS)

GNSS works using the signals received from satellites in the orbit of the earth. The GNSS satellites always transmit right hand circular polarised radio signals. GNSS antennas should always be mounted with the X and Y planes horizontal and the Z plane vertical. Because GNSS uses right hand circular polarisation, the antenna can be freely rotated on the XY plane if it supports right hand circular polarization.

Note that the line of sight to the sky is not just upwards. Satellites cross the sky and can be from just above the horizon to directly above. For this reason, the ideal place to locate a GNSS antenna is where the antenna will have a line of sight to the largest area of the sky possible.

Cellular (GSM/UMTS/LTE), LoRA, PMR, SigFox

The key aspects of these technologies are that:

1. The user will be connecting to the antenna on a base station which is owned by a third-party service provider. This means that the user has no control over one of the two antennas that will be used by the radio link.
2. The distances are typically 100's m to many km's.

One thing that is certain, is the antenna on a base station will be a good quality antenna with vertical polarization mounted vertically at a good elevation. The typical cell tower is 15 to 35 m in height, but could be even taller in rural areas. The highest LoRA installation that the author is aware of is on the BT Tower in London at 180 m. High elevation should allow the radio signal to travel further. But note that that as you approach the base station that there will be a point where the radio signal received from the base station will reduce because the base station antennas beam will be optimised for outwards performance rather than downwards performance.

Because the distance between the antennas is large, even though the signal starts as vertically polarised, there will be many reflected signal paths between a transmitter and receiver. This means that the polarization of the received signal will be mostly random which can make the placement and orientation of the antenna a trial-and-error process for best reception.

For cellular installations, Siretta has the SNYPER range of cellular network analysers that may be used to measure the received signal strength of every cell in range of the tester. A user may use this information to first pick the best cellular network operator for an installation, and then find the bands of operation used by that network operator on the site. This information can be used in the first case to select an antenna that will work best with the cells providing coverage on the site. Multiple measurements over a long period of time will show how reliable the signal is. Then at the point of installation the antenna may be connected to the analyser being used in LiveSCAN mode which allows the received signal strength to be measured in real time. This allows the antenna to be moved around to find the best position for optimal reception. If a directional antenna is used, this is a very good way to make sure that it is pointed in the correct direction.

Bluetooth, IEEE 802.15.4, ISM, WiFi, Zigbee, Z-Wave

The key aspects of these technologies are that

1. The user is likely to control and operate both ends of the radio link.
2. The distances are typically 1 m to 10's m.

Because the distances involved are small, the radio network is likely to be in a home or building. In such cases, the base station/Access Point being connected to could be mounted on a wall, or the ceiling. Indeed, it could be that the radio link is travelling vertically if the ends of the radio link are on different floors. In this case the radiation pattern of both antennas needs to be considered if the link distance of the radio standard being used is long. The full three-dimensional model of the antenna may need to be considered as the radio links created may be both above and below the antenna, as well as on the same level.

Polarization also needs to be considered. Where the radio link is a short distance, there are unlikely to be many reflected radio signals and so the polarity of the signal leaving the transmitter is likely to be the same as that arriving on the receiving antenna. While almost all antennas are vertical polarisation, that is vertical polarisation with respect to the XYZ orientation diagram provided in the data sheet. An antenna mounted at a different angle will have a correspondingly angled polarization that ideally needs to be matched at the antenna at the other end of the link.

Appendix A

List of Frequency Bands by Application

6LoWPAN
See IEEE 802.15.4

Bluetooth
Bluetooth devices operate in the unlicensed 2.4 GHz Industrial, Scientific and Medical (ISM) band. See https://www.bluetooth.com/specifications/specs/core-specification/

Cellular
For GSM, UMTS & LTE, see 3GPP ‘TS 136 101’ which can be downloaded as ‘ETSI TS 136 101’ from https://www.etsi.org.

For 5G, see 3GPP ‘TS 38.101’ which can be downloaded as ‘ETSI TS 138 101’ from https://www.etsi.org. TS 38.101-1 covers the FR1 bands, TS 38.101-2 covers the FR2 bands, and TS 38.101-3 covers the E-UTRA bands.

GNSS

GPS
See ‘IS-GPS-200’ for detail of the L1 & L2 bands, available at https://www.gps.gov/technical/icwg/IS-GPS-200M.pdf

GLONASS
See ‘GLONASS Interface Control Document, Navigational radio signal in bands L1, L2’, available at http://russianspacesystems.ru/wp-content/uploads/2016/08/ICD_GLONASS_rus_v5.1.pdf (in Russian)

BeiDou
See various ‘BeiDou Navigation Satellite System Signal In Space Interface Control Documents’ (covering the different deployment phases), available at http://en.beidou.gov.cn/SYSTEMS/Officialdocument/index_1.html

Gallileo
See ‘Galileo - Open Service - Signal In Space Interface Control Document’ available at https://www.gsc-europa.eu/electronic-library/programme-reference-documents

NavIC
See ‘IRNSS Signal-in-Space ICD for SPS’, available at https://www.isro.gov.in/sites/default/files/irnss_sps_icd_version1.1-2017.pdf

QNSS
See 'IS-QZSS-PNT-004' available at https://qzss.go.jp/en/technical/ps-is-qzss/ps-is-qzss.html

IEEE 802.15.4
See 'IEEE 802.15.4-2020 - IEEE Standard for Low-Rate Wireless Networks' available at https://standards.ieee.org/standard/802_15_4-2020.html

ISM
See Paragraphs 5.138 and 5.150 of Chapter II of the Radio Regulations 2020 edition, volume one, available at https://www.itu.int/en/myitu/Publications/2020/09/02/14/23/Radio-Regulations-2020?sc_camp=DD249A18F65340498C7674FA167CAC94

LoRa
See RP002-1.0.3 LoRaWAN® Regional Parameters, available at https://lora-alliance.org/wp-content/uploads/2021/05/RP-2-1.0.3.pdf

MiWi
See IEEE 802.15.4

PMR / LMR
This encompasses all forms such as NXDN, TETRA, MPT-1327, APCO 25 and DMR. This is very country specific, but usually the frequency bands used will be in the range 130 MHz through 950 MHz.

Sigfox
See 'Sigfox connected objects: Radio specifications' available at https://build.sigfox.com/sigfox-device-radio-specifications

Thread
See IEEE 802.15.4

Snap
See IEEE 802.15.4

WiFi
See '802.11-2020 - IEEE Standard for Information Technology--Telecommunications and Information Exchange between Systems - Local and Metropolitan Area Networks--Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications' available from https://ieeexplore.ieee.org/document/9363693

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WirelessHART

See IEEE802.15.4

Zigbee

See IEEE 802.15.4

Z-Wave

See Z-Wave Alliance Frequency and Region List available at https://sdomembers.z-wavealliance.org/document/dl/965

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