# **RF Survival Guide - Part 1**

## **Basic Antenna Concepts**

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Working as a Radio-Frequency (RF) Engineer, I know first hand that the world of RF can seem like a maze of jargon and complex concepts. Whether you’re an amateur radio enthusiast or just someone curious about how wireless communication works, understanding some of the basic terminology can feel like a daunting task. In this guide, I’ll break down some of the most common RF concepts and explain them in plain language, making it easier to navigate this crazy and complex world of electromagnetic waves and to ease the understanding of much of the RF content posted here on Medium.

**Knowledge Disclaimer:**Although this article is directed to RF newbies, I assume the reader is well versed in basic electrical concepts such as impedance, resistance and reactance.

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## Resonant Frequency

Frequency is the number of times a wave oscillates per second. It is measured in Hertz (Hz). Radio frequencies officially go up to 3THz, but, truly, this is a kind of arbitrary value defined by the Institute of Electrical and Electronics Engineers (IEEE) as terahertz wireless communications are currently in the early research and development stage rather than widespread commercial deployment. Frequencies higher than 3THz are considered to be in the infrared part of the electromagnetic spectrum and beyond. Keep in mind that these hard limits are just human-created categories.

The resonant frequency of an antenna is the frequency at which the antenna naturally oscillates (electrically speaking, of course) and efficiently radiates or receives electromagnetic waves. At this frequency, the antenna has minimal reactance (imaginary impedance is close to zero and only real impedance remains), meaning it is well-matched to the system and minimizes power loss (at this frequency, the antenna does not store any energy due to minimal reactance and radiates all the energy it is fed).

## Antenna Bandwidth

Antenna Bandwidth, not to be confused with network bandwidth which measures the capacity of a communication channel (and is the most common colloquial use of the word), is the range of frequencies within which an antenna works well. That is, the frequency range over which the antenna is considered to be impedance matched to the feed line, the gain is within expected values and the radiation pattern is not distorted. When operating outside the bandwidth it was designed to, an antenna can work differently than expected. For example, directional antennas might start to behave more omnidirectionally, with less gain and start to reflect power back to the transmitter due to poor impedance matching, with risk of damaging the device.

## Bell (B) and Decibel (dB)

The Bell (B) is not a unit. It is the base 10 logarithm of a ratio between two values (typically a measured value and a reference value). It is rarely used in practice because it is too large for most applications. A Decibel (dB) is one-tenth of a Bell and much more commonly used. Decibels are widely used in the RF context because many measured values span several orders of magnitude. The decibel scale compresses large numbers into a manageable range and simplifies calculations (because, in dB, multiplication becomes addition, making it easier to compute gains and losses in cascaded systems).

## Power Values (dBm)

As I explained before, in the RF world, power values can span several orders of magnitude. For example, radiated power in a certain direction decays quadratically with distance (i.e. it changes a lot even for relatively small distance variations). As a result, the use of decibels is recommended to compress results into a manageable range. This is also true for many other antenna-related quantities.

dBm is a unit of power relative to 1 milliwatt. So it is ten times the logarithm of the ratio between a certain value and 1 milliwatt. In other words, dBm refers to milliwatts in decibel scale.

## Radiation Efficiency and Total Efficiency

Radiation efficiency is the ratio of the power radiated by an antenna to the total input power supplied to it, considering only conductor and dielectric losses. Total efficiency includes both radiation efficiency and mismatch losses due to impedance mismatches, such as between the antenna and the feed line. Much more could be said about this topic (And any of the others, really), including explaining radiation resistance. But I don’t want to make this a dense article. I would say this is enough for any beginner regarding antenna efficiency. Many times, when RF engineers talk about efficiency they do not specify which one, contributing to the terminology mess we have in the field.

## Directivity, Gain and Realized Gain

Directivity measures how well an antenna focuses energy in a specific direction compared to an isotropic radiator (an imaginary antenna that equally radiates in all directions). It is a theoretical property and does not consider losses.

Gain represents the effective radiated power in a given direction. It includes radiation efficiency.  
Realized Gain includes both radiation efficiency and impedance matching losses. It is the most practical of the three.

Many times, when RF engineers say “gain” without specifying a direction we typically mean maximum gain (in the strongest radiation direction). We also typically mean realized maximum gain, simply because that’s the one we actually can measure (gain and directivity are only given by electromagnetic simulation software). This just adds up to the maze of terminology jargon I talked about in the beginning.

The terms covered in this section are useful to characterize how well an antenna focuses energy in a specific direction. Some we want to radiate everywhere, others quite the opposite.

## Gain Values (dBi, dBd and dBic)

Gain values are expressed in different reference units: dBi, dBd, and dBc, each comparing antenna performance to a different standard.

dBi (decibels relative to an isotropic antenna) is the most common and compares gain to a theoretical isotropic radiator, making it useful for general antenna characterization.

dBd (decibels relative to a dipole) compares gain to a half-wave dipole antenna.

dBic is used for circularly polarized antennas, referenced to an ideal isotropic circularly polarized radiator.

An antenna with a gain of 12 dBi means it radiates 12 dB more power in its main direction compared to an ideal isotropic antenna that radiates equally in all directions.

## Polarization and Polarization Loss Factor

Polarization refers to the electric field’s orientation in the electromagnetic waves that are transmitted by the antenna. It is defined for a given direction, however, when the direction is not stated, the polarization is taken to be the polarization in the direction of maximum gain. The orientation of the electric field can be constant or change over time. Orienting an antenna made of linear conductors (linear antenna) vertically will result in vertical polarization, while orienting the same antenna horizontally will result in horizontal polarization. For non-linear antennas or for arrays of linear antennas that are not aligned, the orientation of the electric field changes as the wave travels through space. If the electric field vector movement in time describes an ellipse or circle, polarization is considered elliptical and circular, respectively. Antenna polarization is very important, because when the receiving antenna’s polarization matches the one of the transmitted wave, there is optimum reception. Otherwise, especially for linear antennas that are orthogonally oriented, reception will be poor. For circularly polarized antennas, signals with either vertical or horizontal polarization can be received, at the cost of a 3 dB reduction in signal strength (and vice-versa). The Polarization Loss Factor (PLF) represents the amount of energy lost due to the mismatch between the polarization vector of a receiving antenna and the polarization vector of an incident wave.

That should be enough for a beginner to explore for days! I could really see a series coming out of this article, especially when we have so much RF-related stuff to talk about, such as Signal-to-Noise Ratio, modulations, S-Parameters, etc… Let me know of your interest in the comments!

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